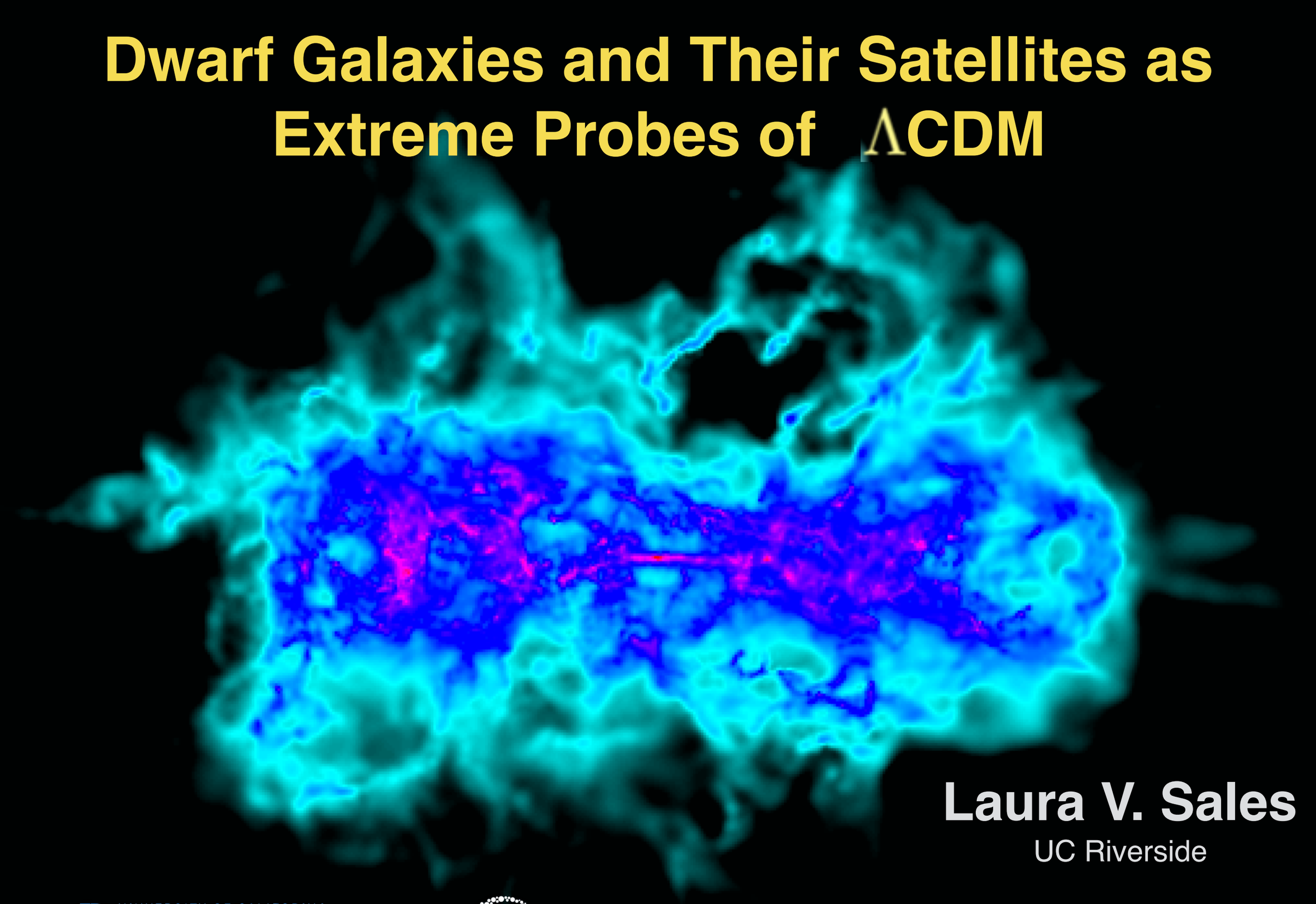
Dwarf Galaxies and Their Satellites as Extreme Probes of ΛCDM



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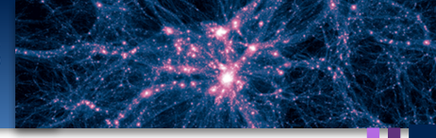


1. Predictions from LCDM: Halo Abundance & Substructure

Lessons from the LMC

Dwarf galaxies and their satellites

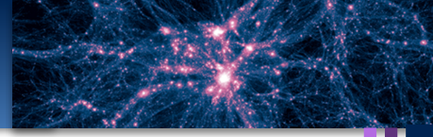
2. Assembly of dwarf galaxies in Clusters

What are the progenitors of dE?

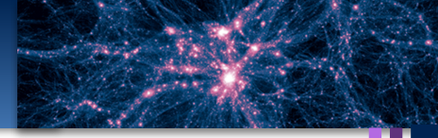
3. Constraining the DM content of dwarfs

The Baryonic Tully Fisher relation

4. Conclusions & Future Plans



Dwarfs come in many sizes…



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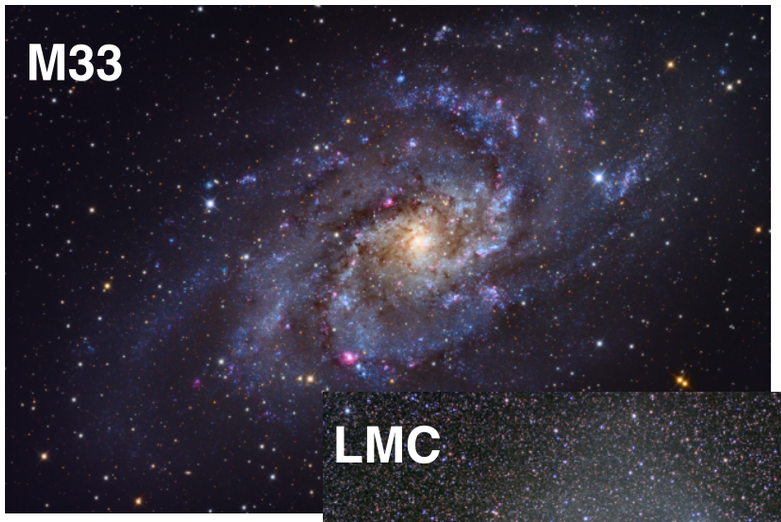
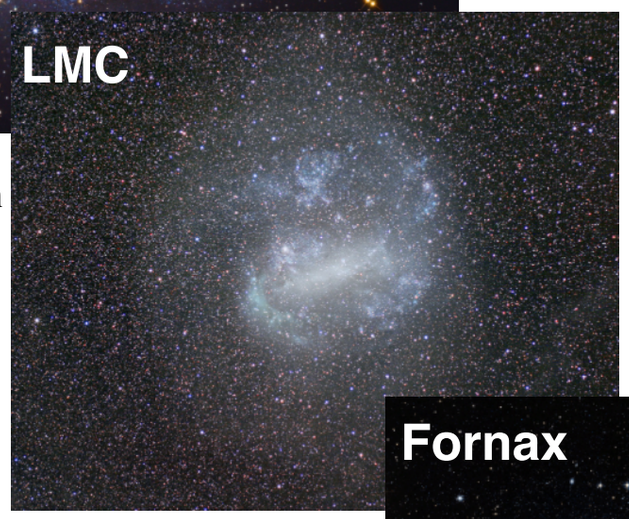
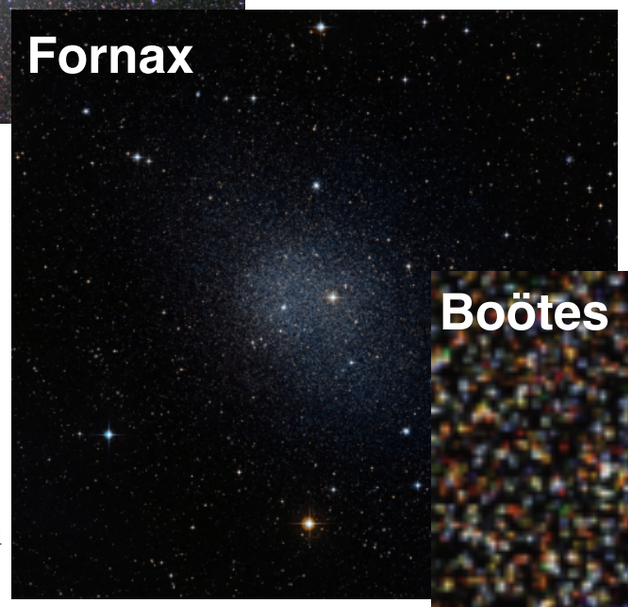


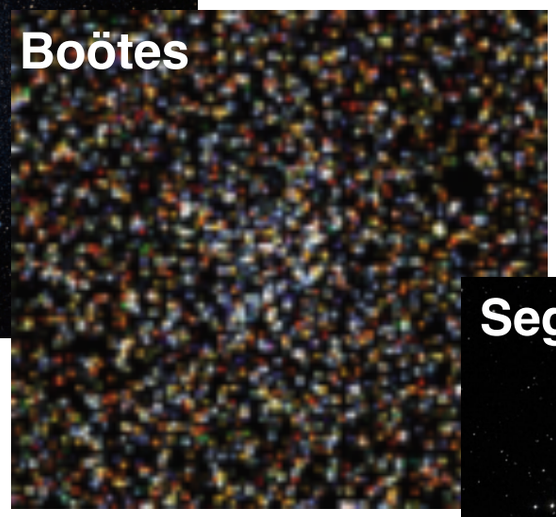
$2.9 \times 10^9\ M_{sun}$



$1.5 \times 10^9\ M_{sun}$



$2 \times 10^7\ M_{sun}$



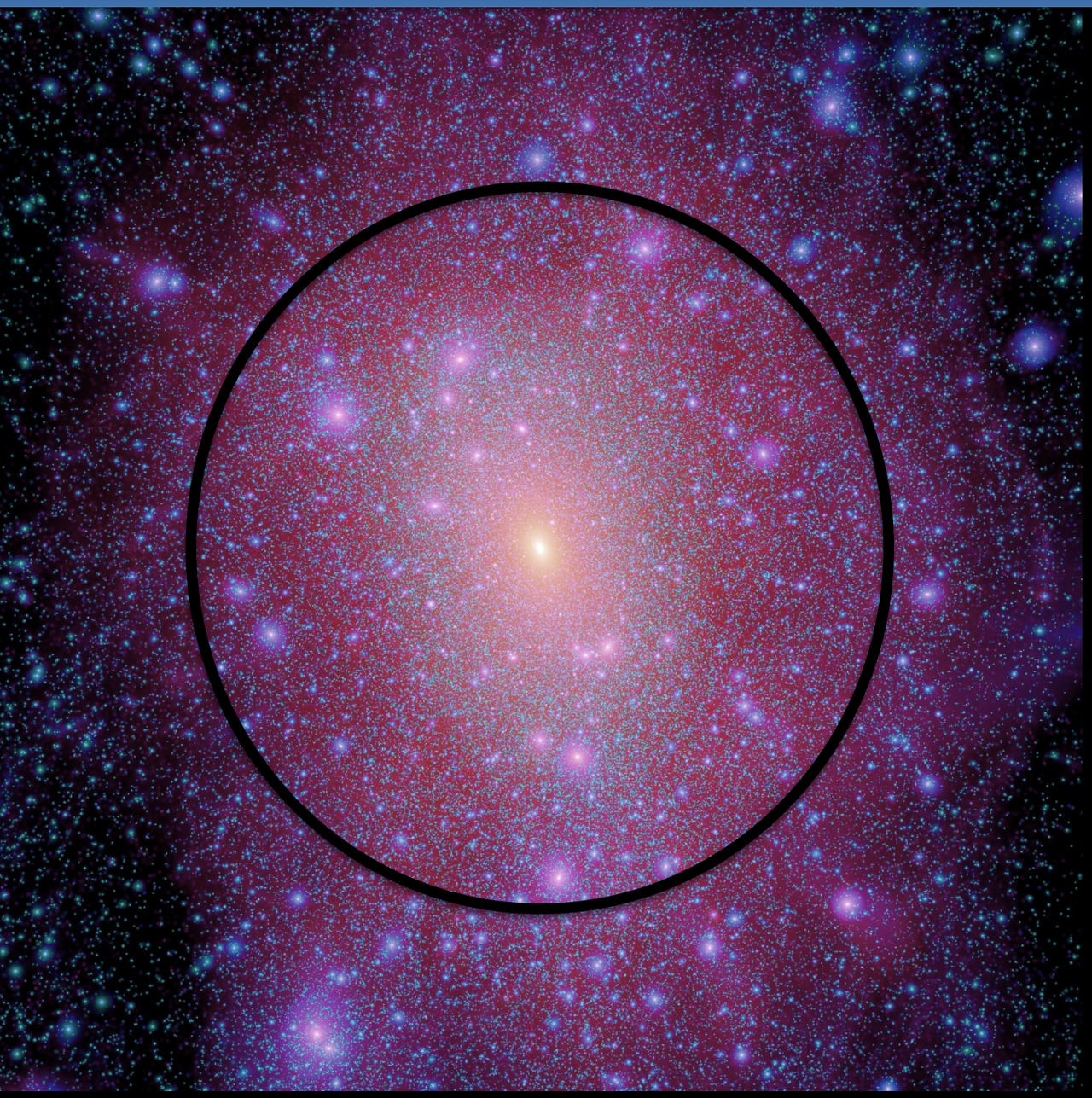
$3 \times 10^4\ M_{sun}$

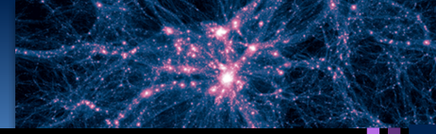
$\sim 10^3\ M_{sun}$

DM content

Stellar Mass

1. Predictions from LCDM I: Abundance





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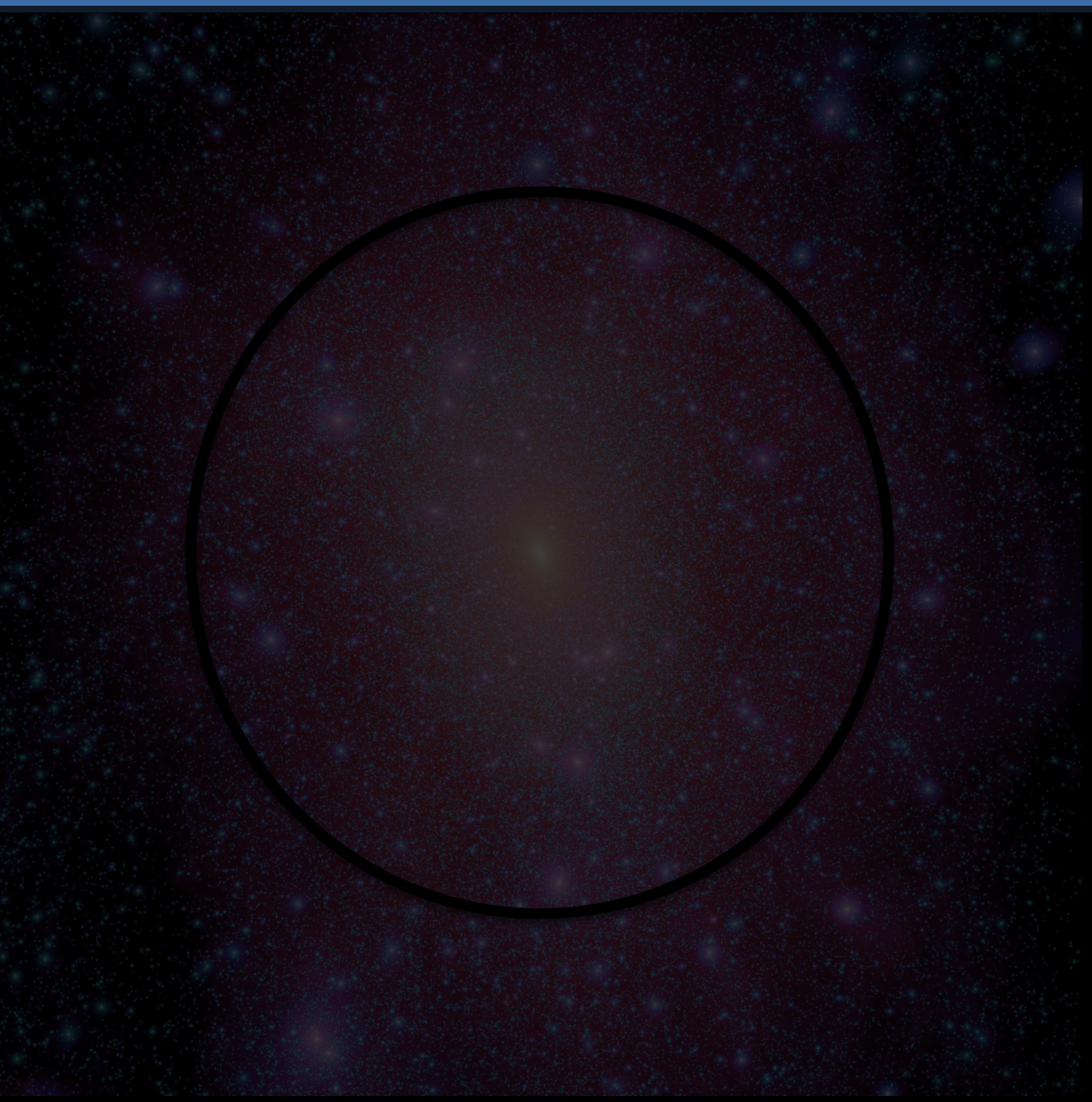

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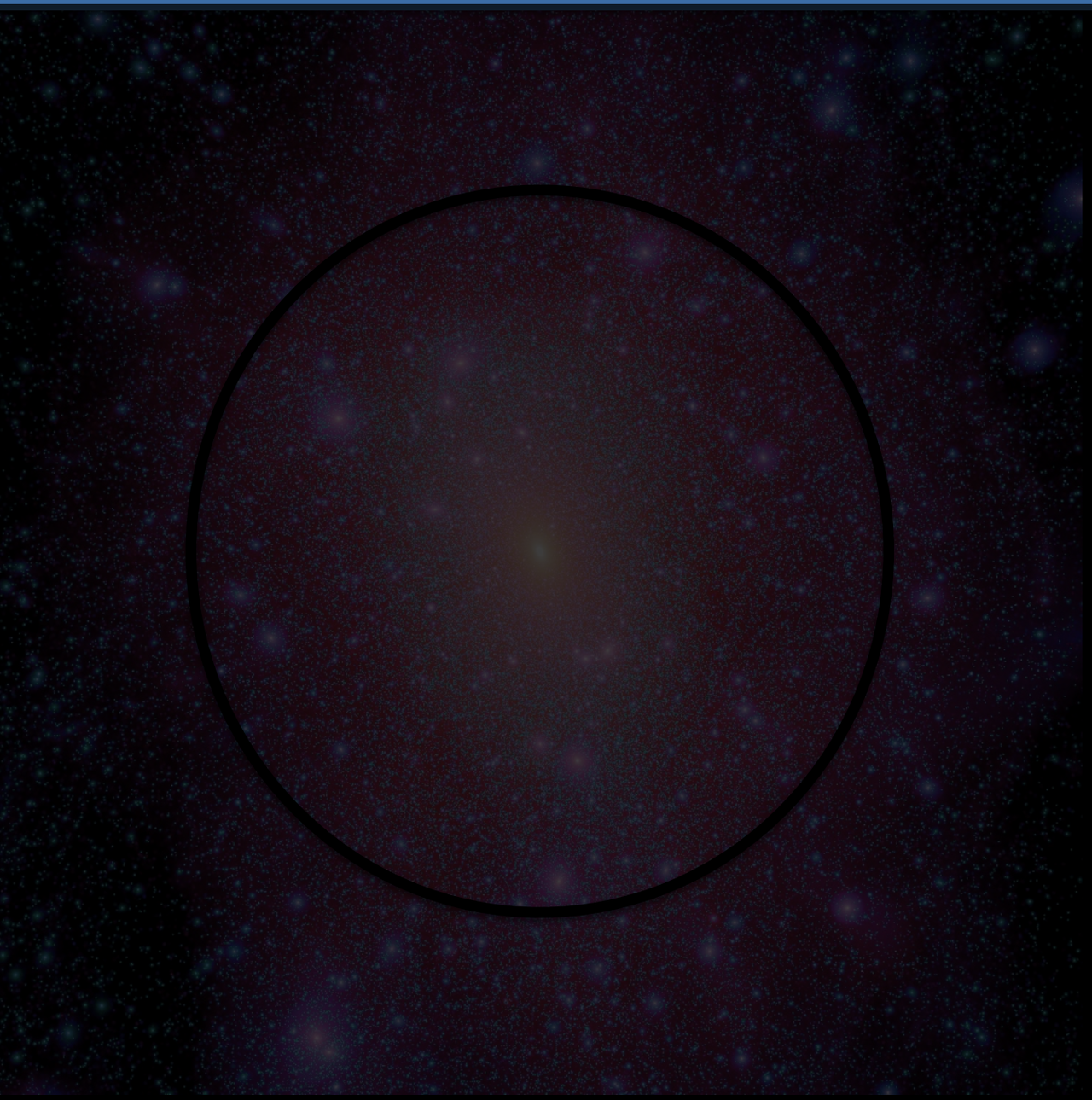

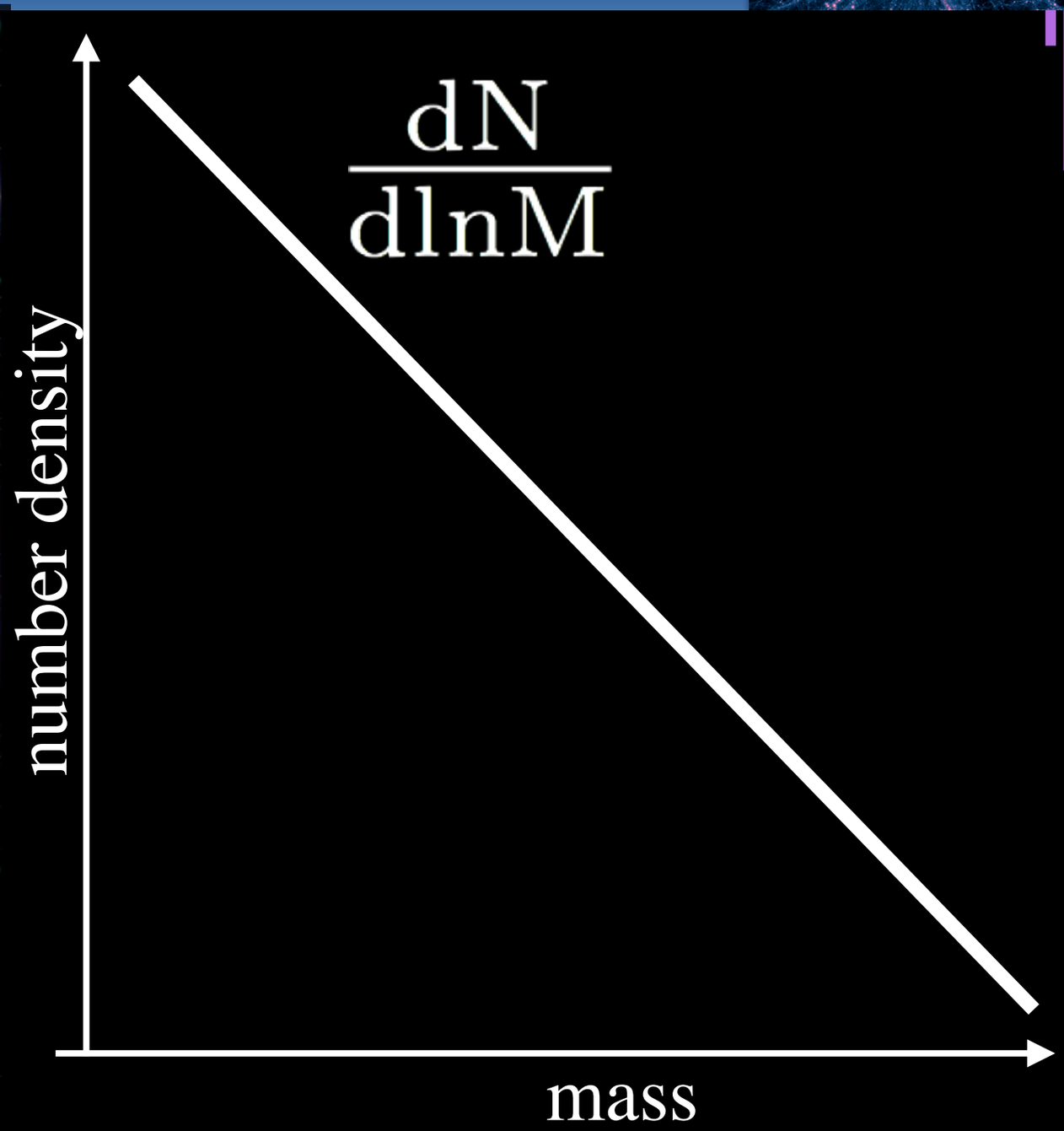

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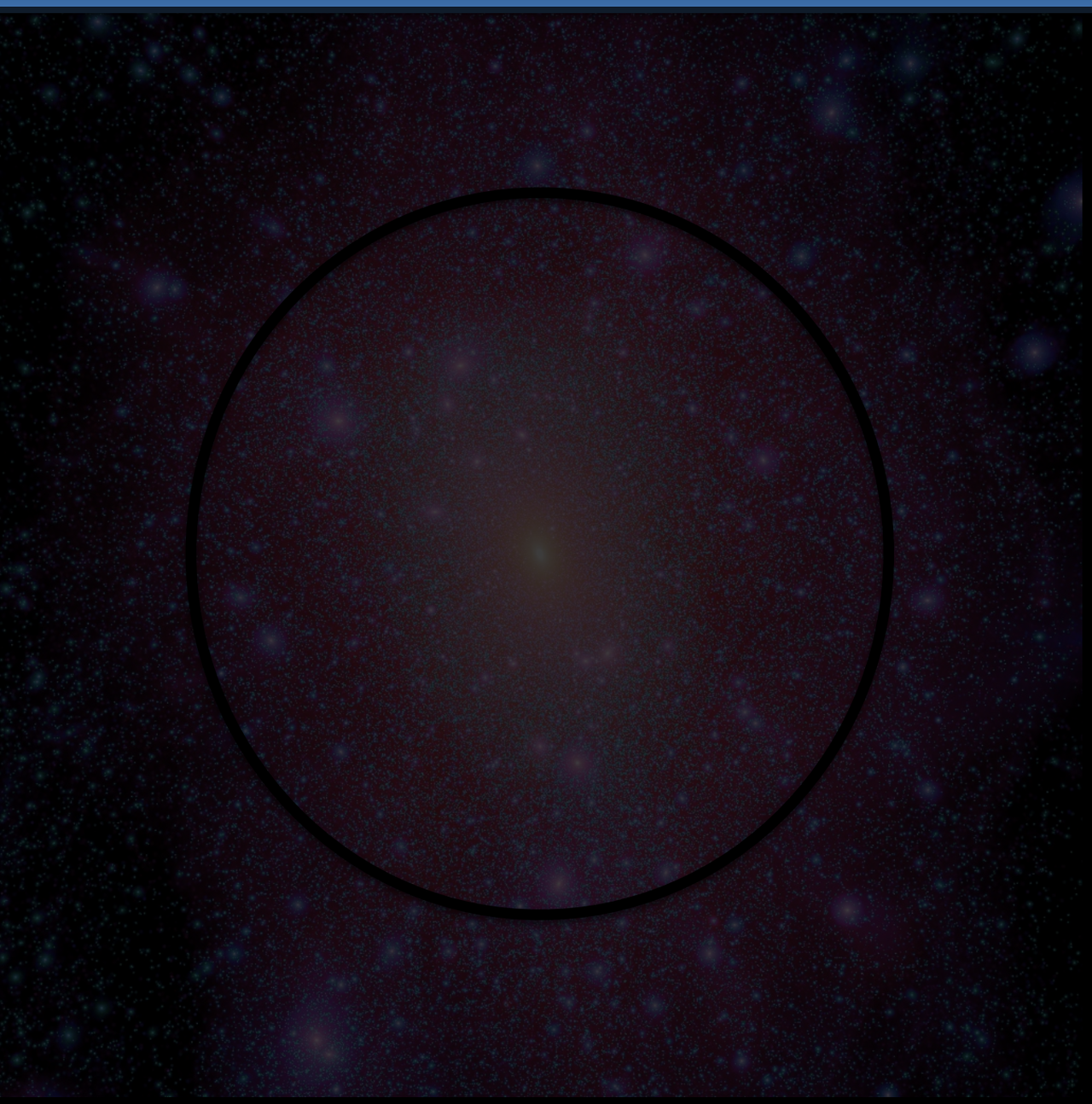

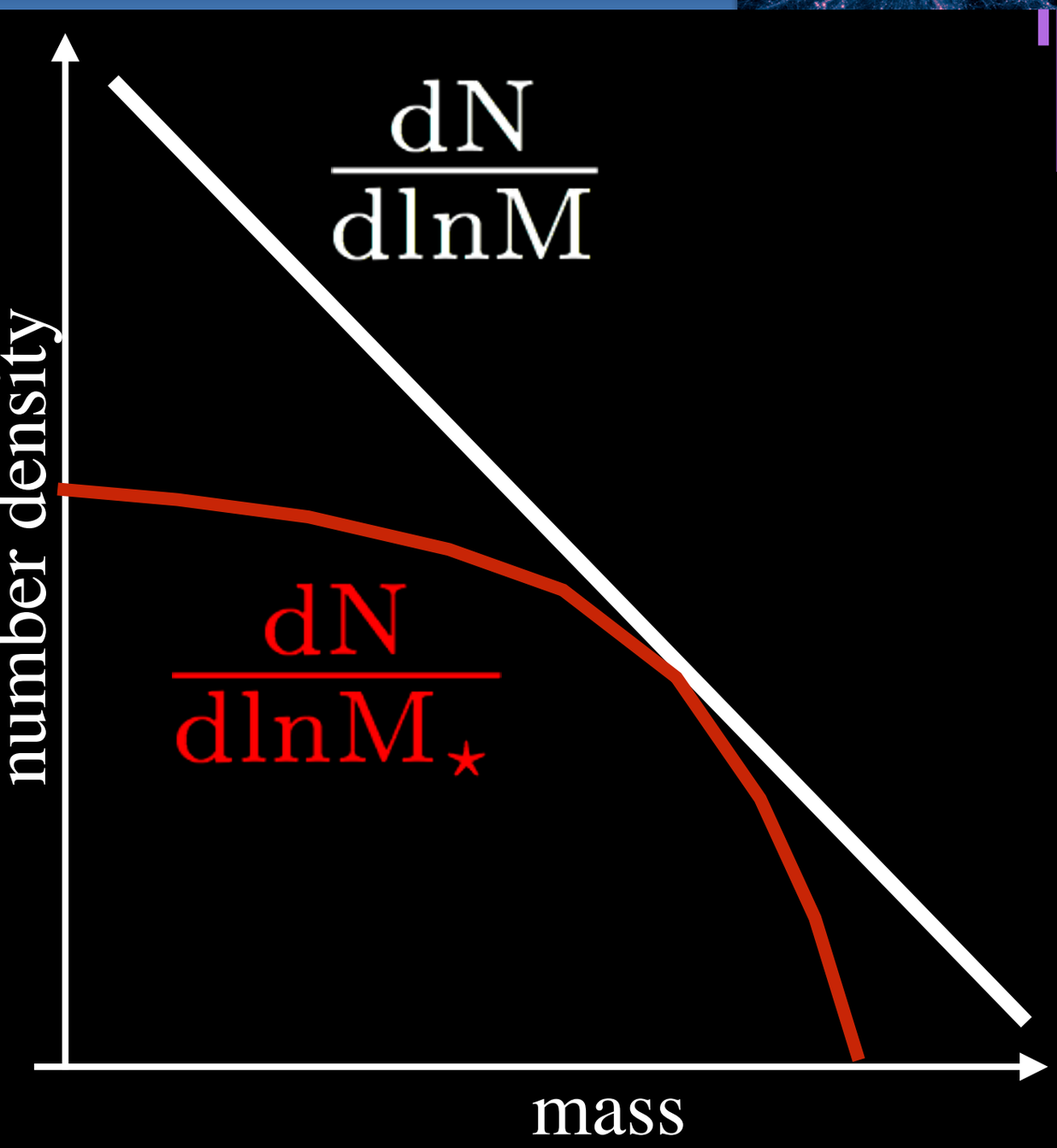

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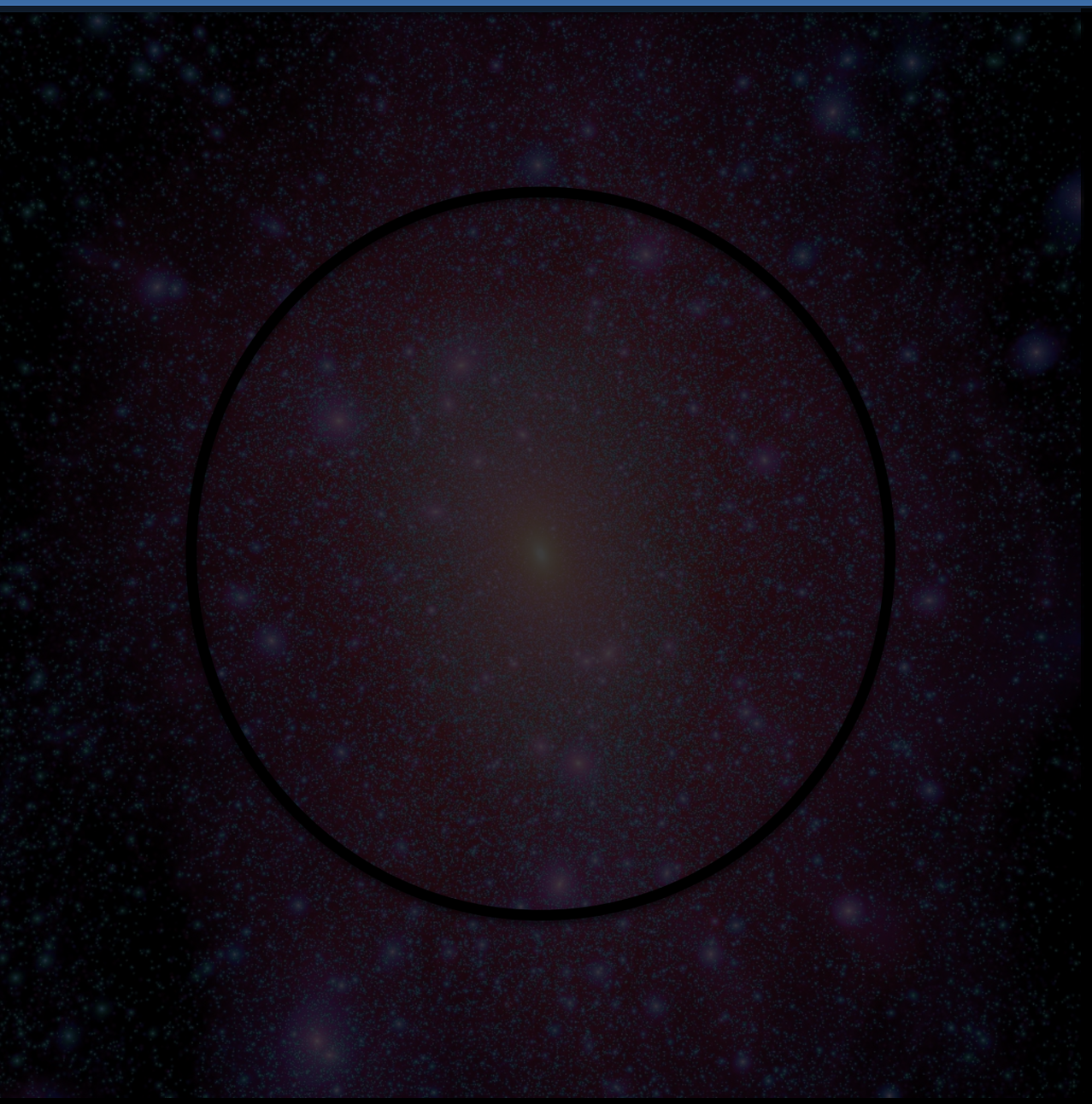

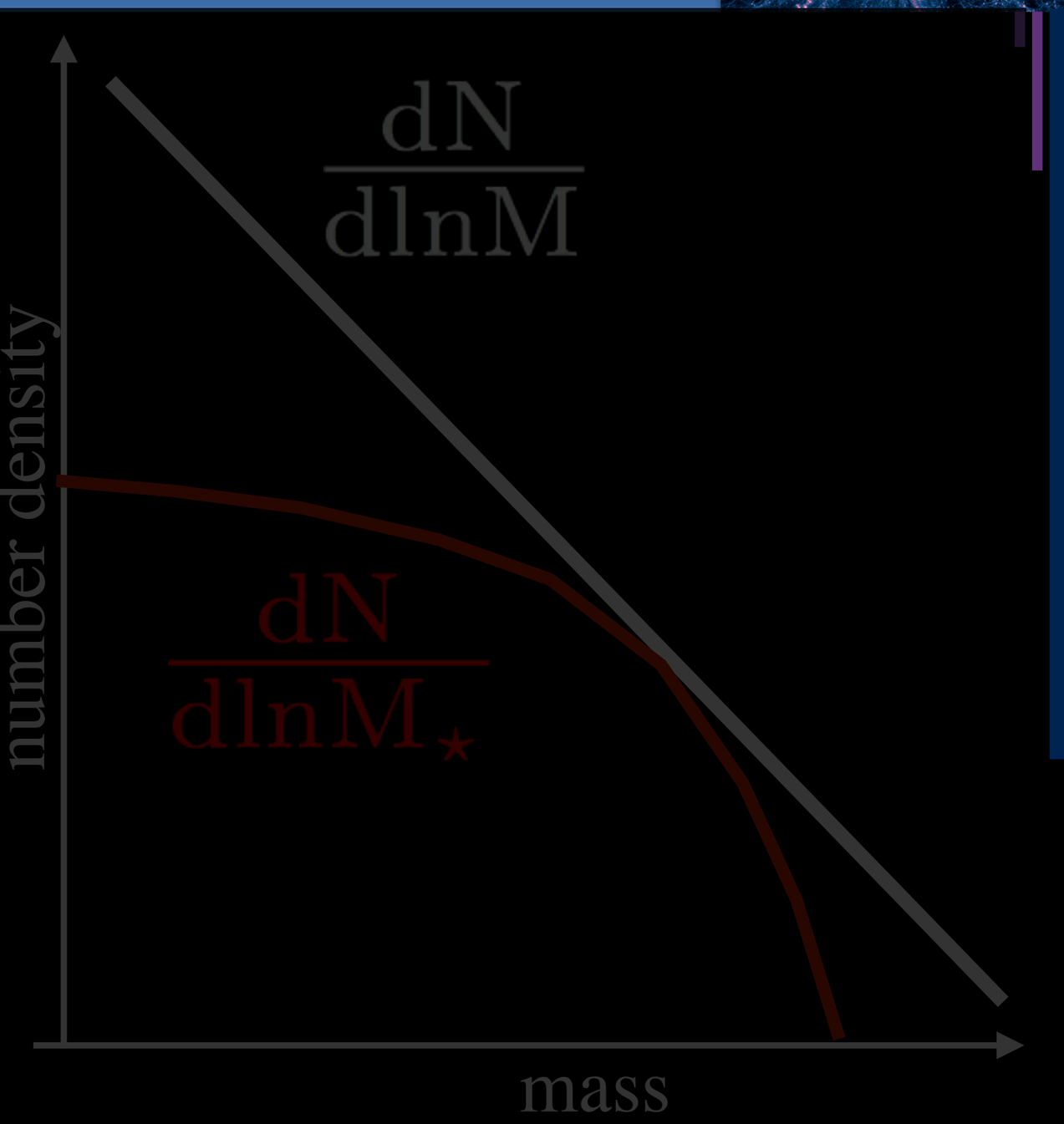

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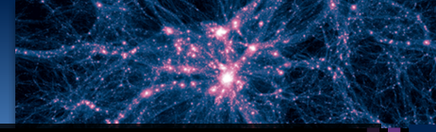
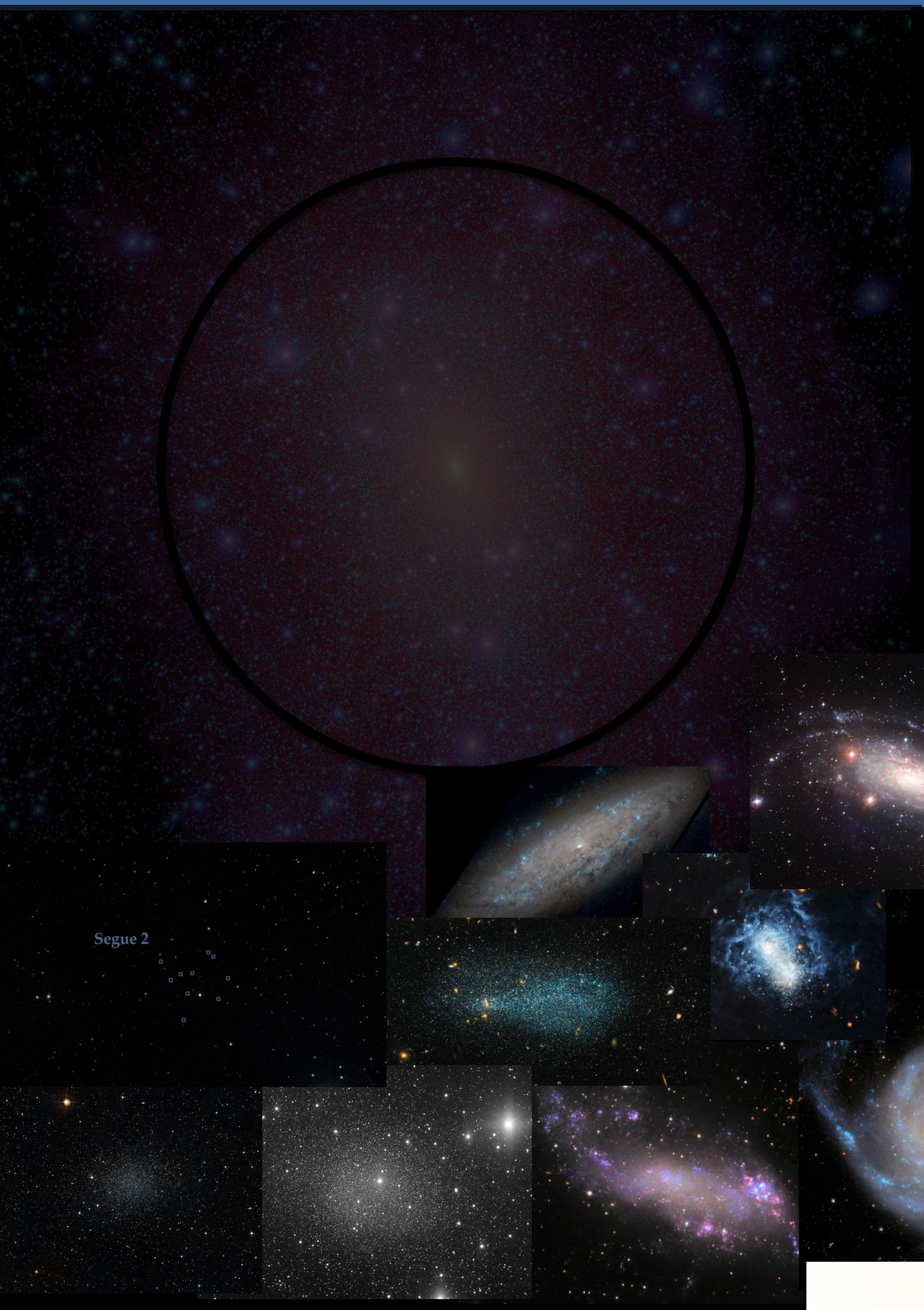
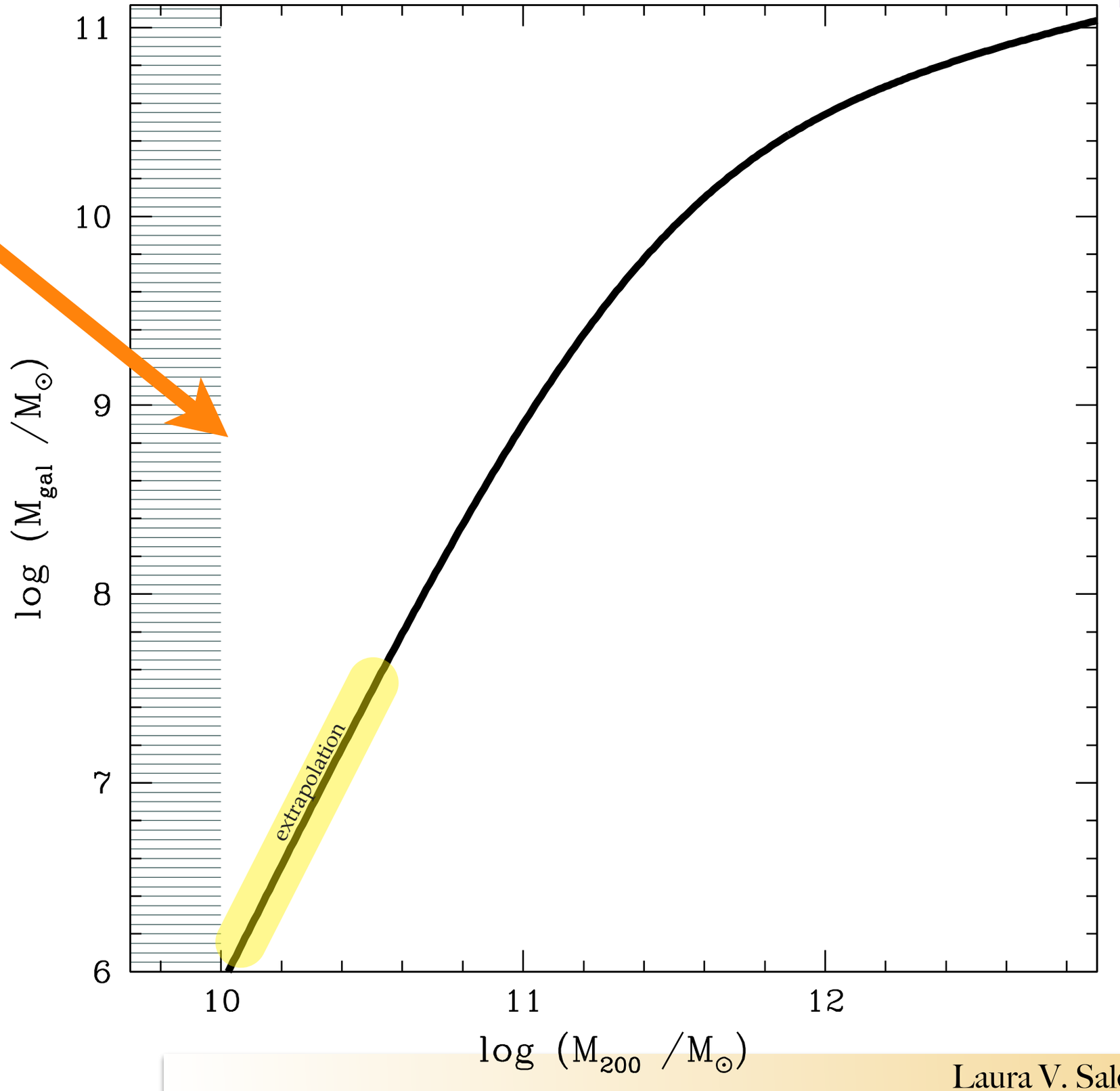




The $M_* - M_{halo}$ relation

Galaxy formation increasingly inefficient toward low mass end



(e.g., Moster+ 2010, Guo+ 2010, Behroozi + 2011, Moster+ 2012, Behroozi+ 2012)

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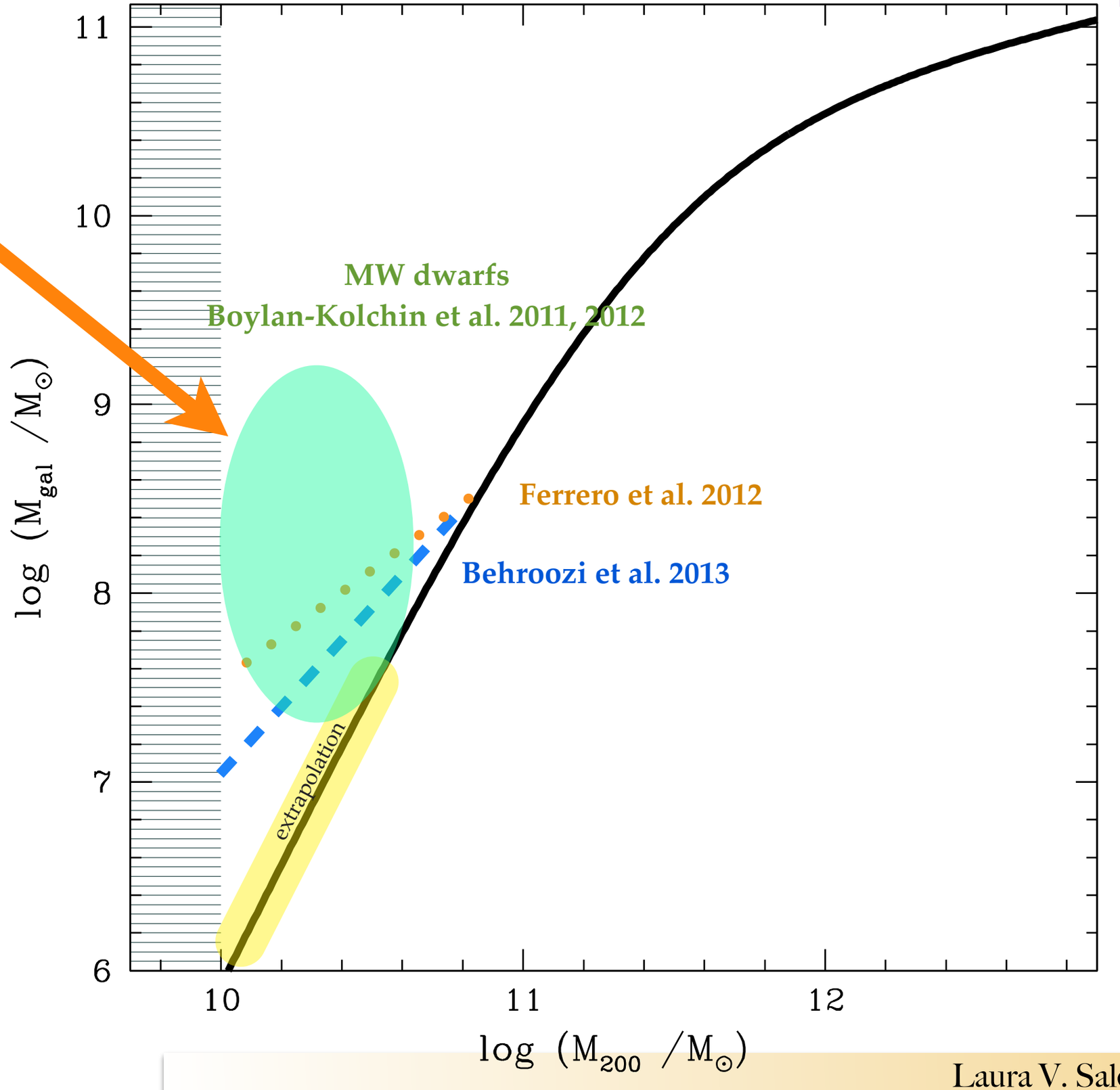

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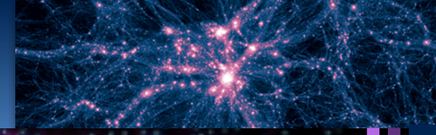

LCDM predictions II: Substructure

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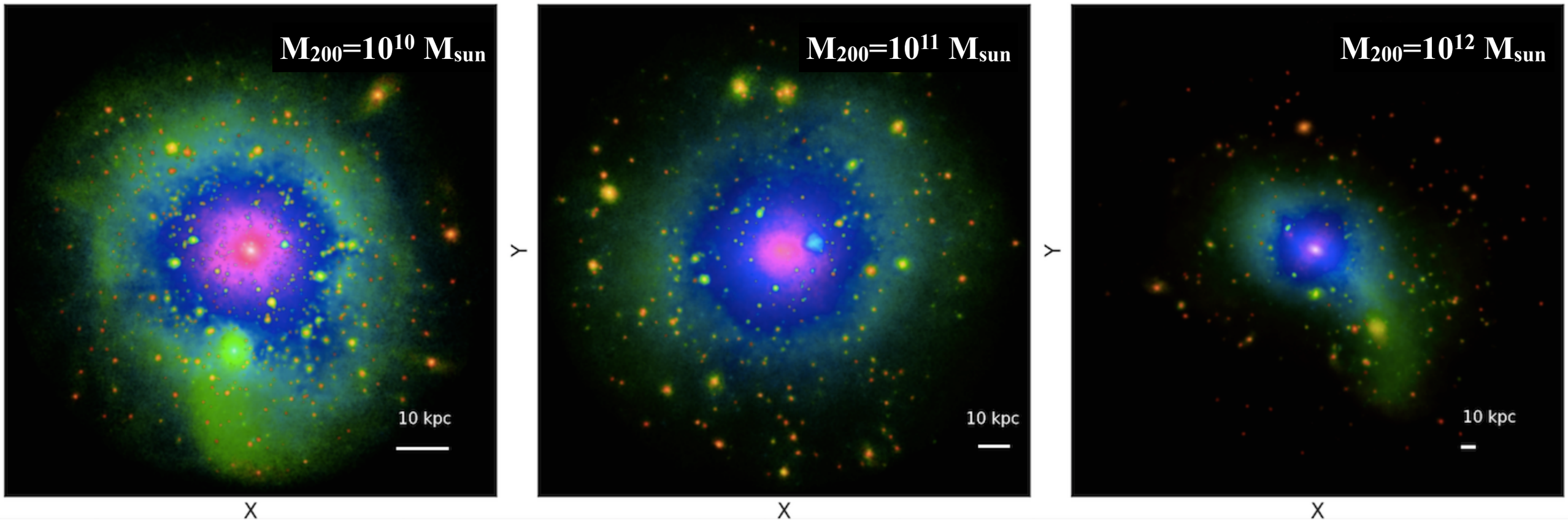
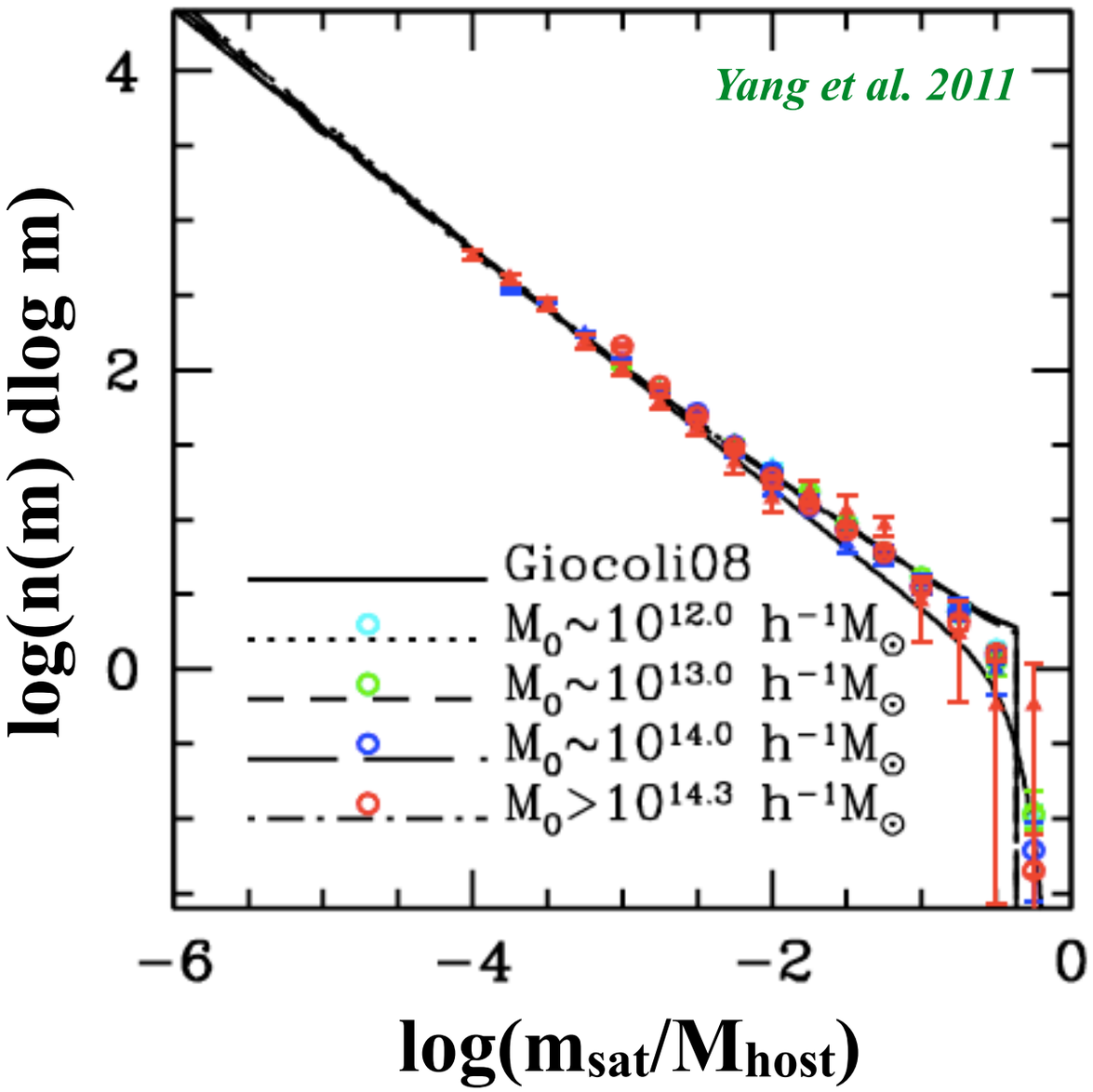
Substructure is expected around ALL galaxies…



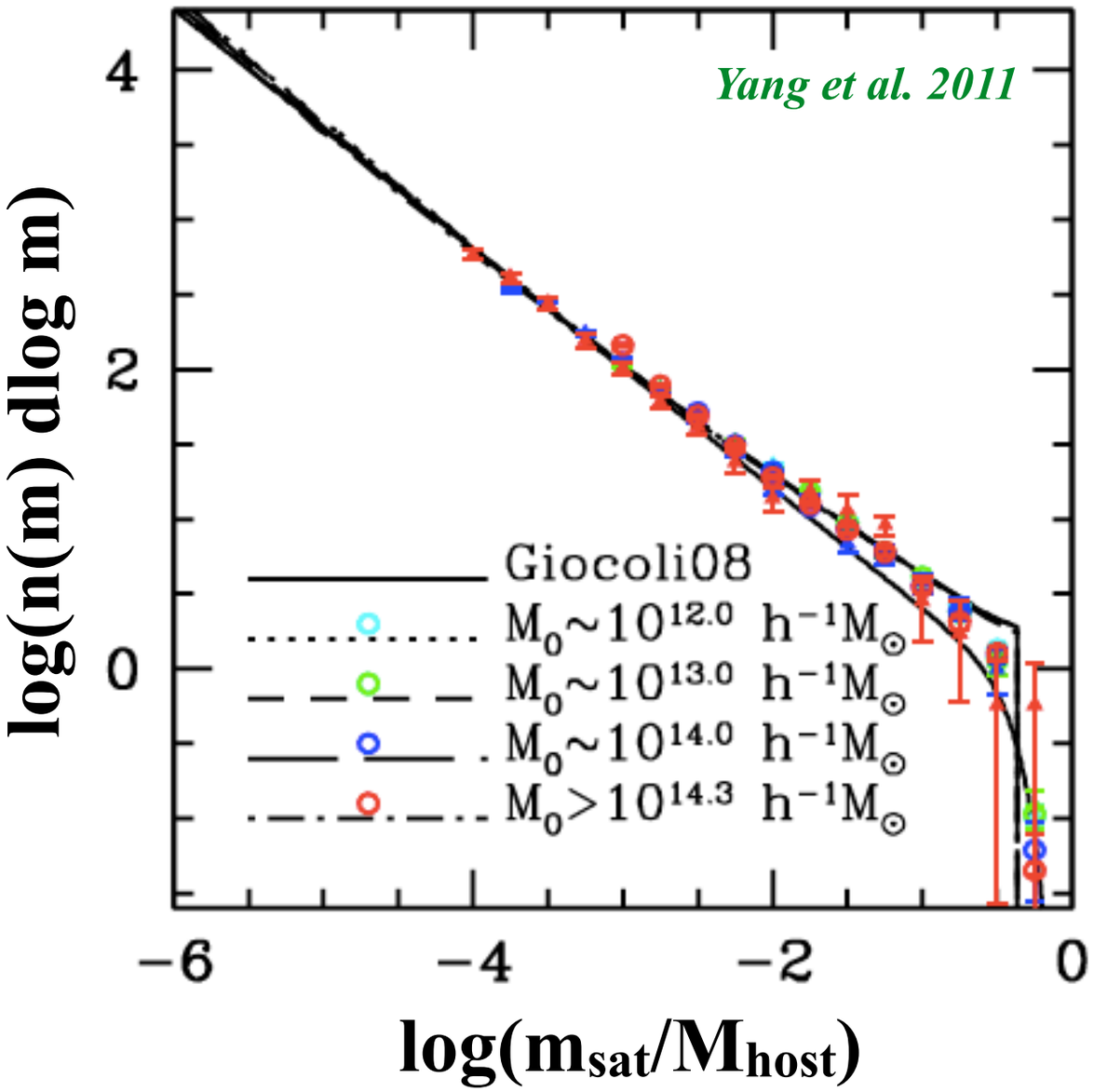
SMC-like halo **LMC-like halo** **MW-like halo**

The subhalo mass function is independent of host mass

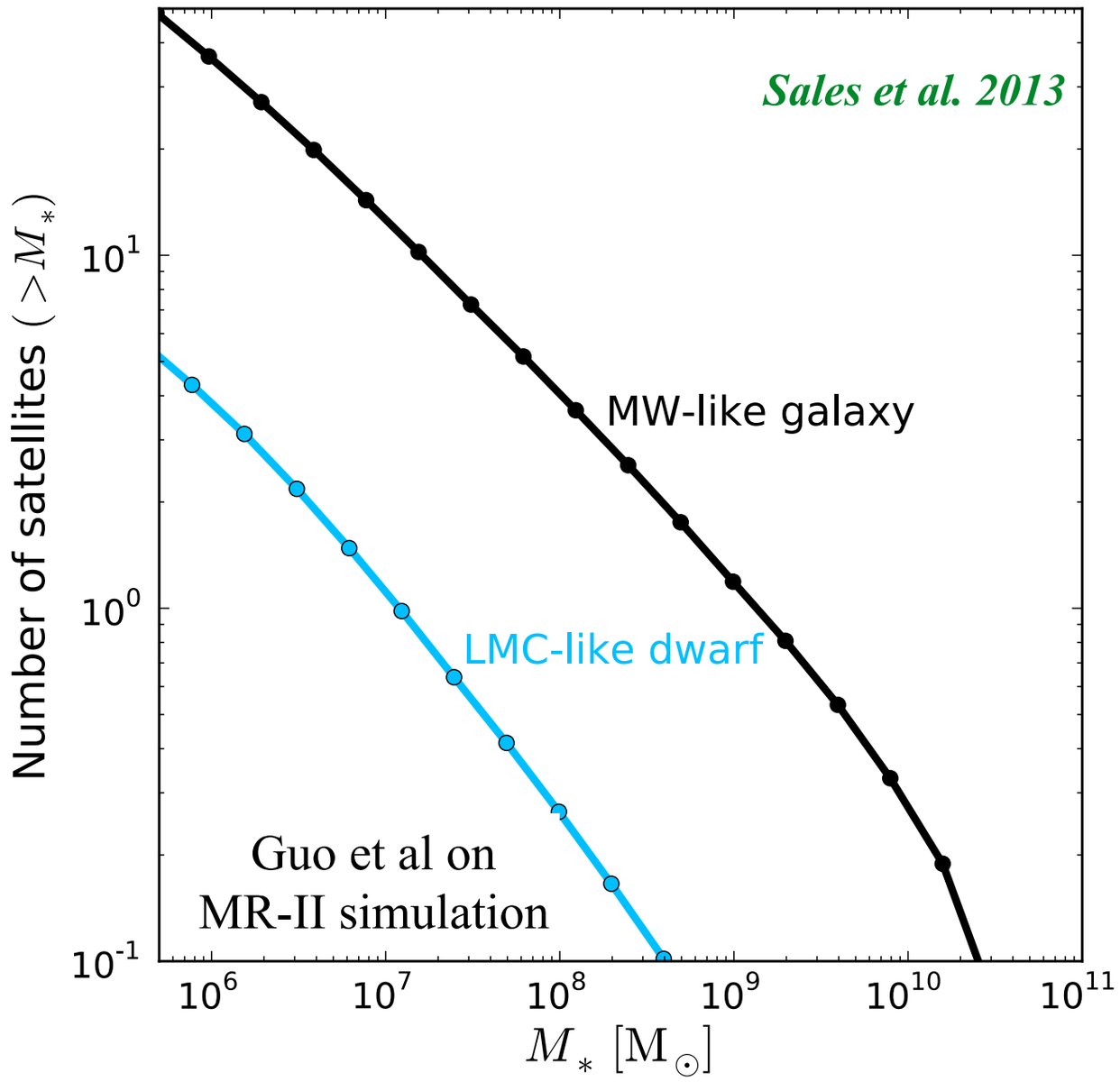


Dark Matter

The subhalo mass function is independent of host mass

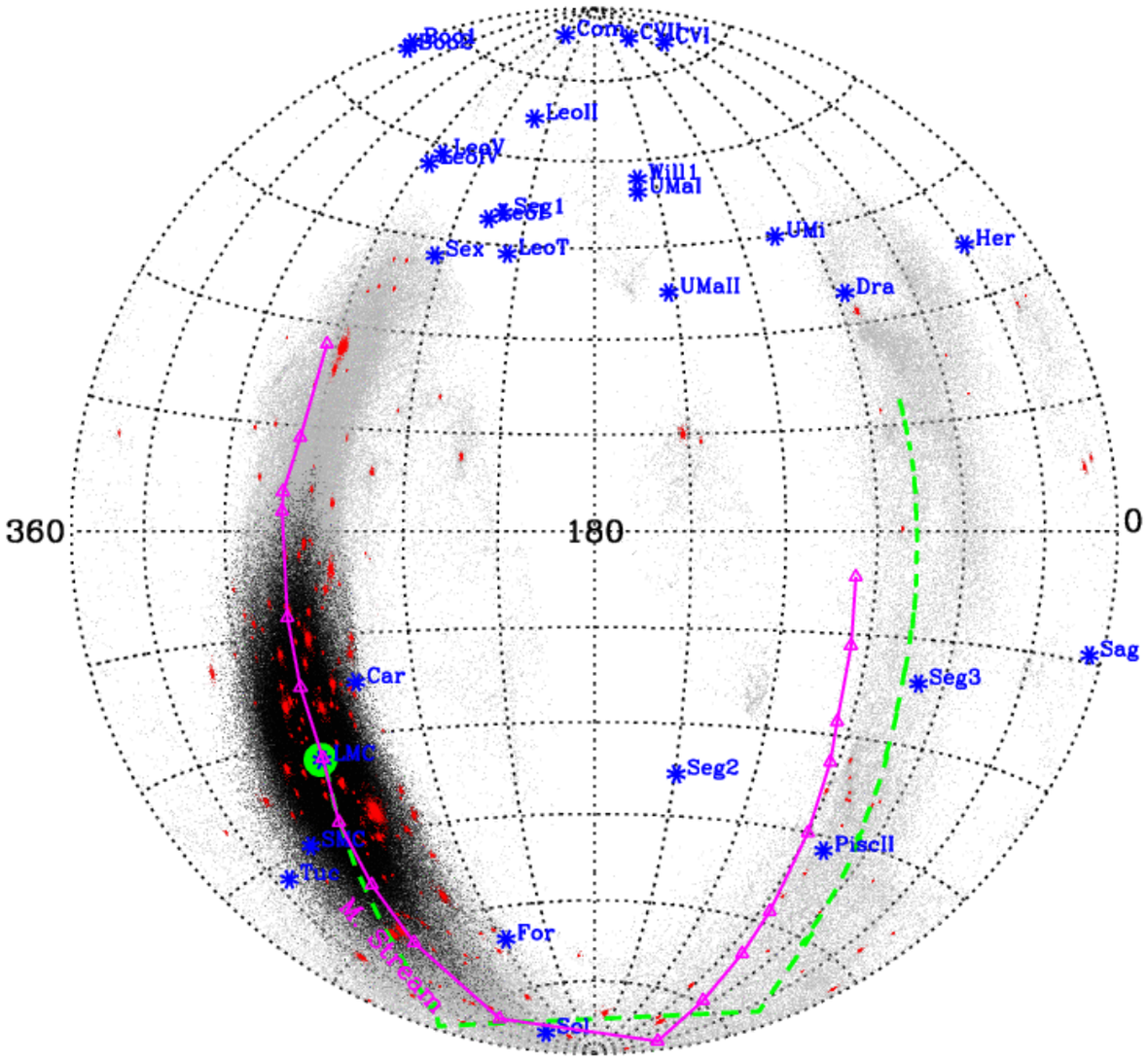


Dark Matter

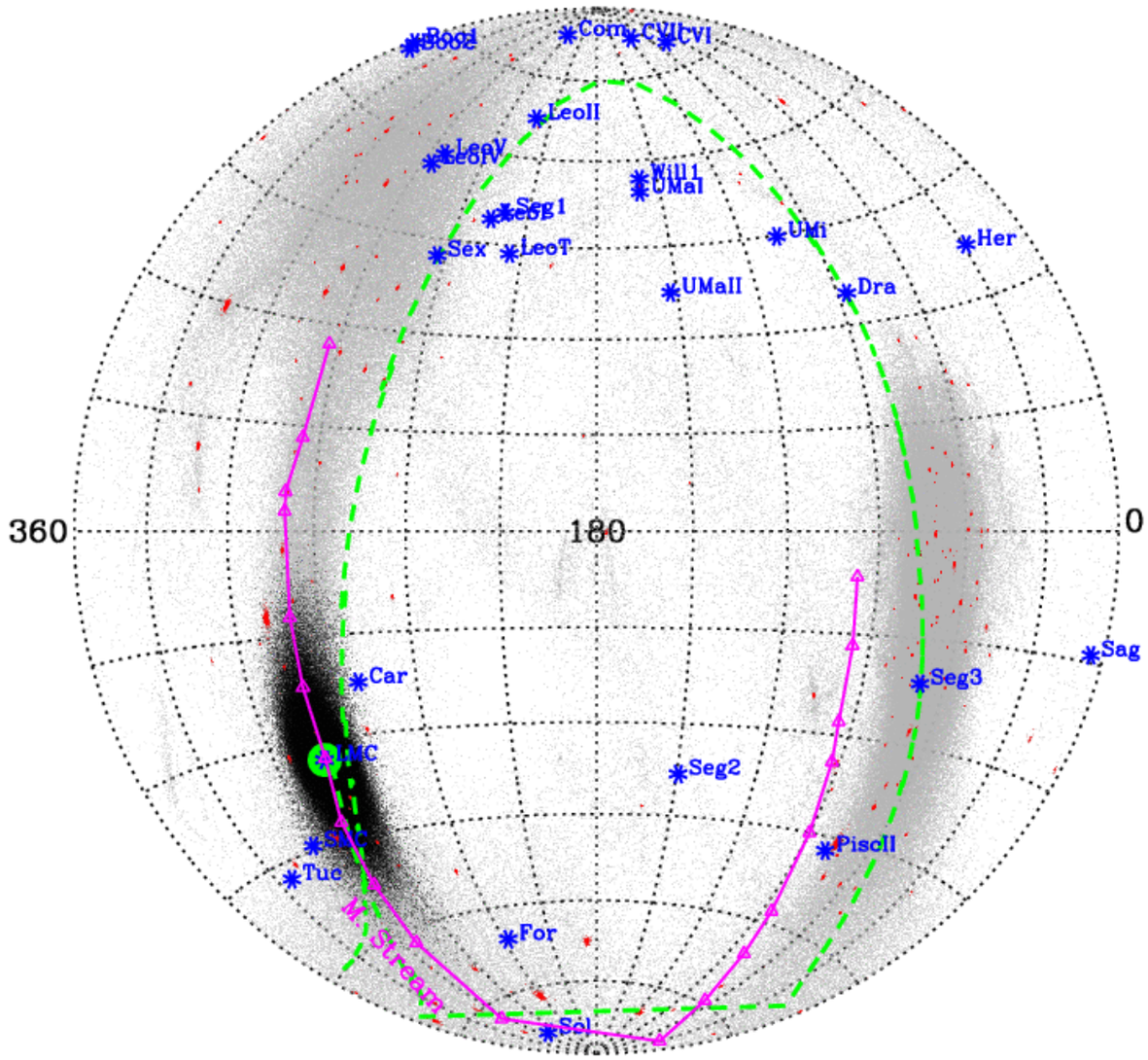


Stars

The satellite companions of the LMC



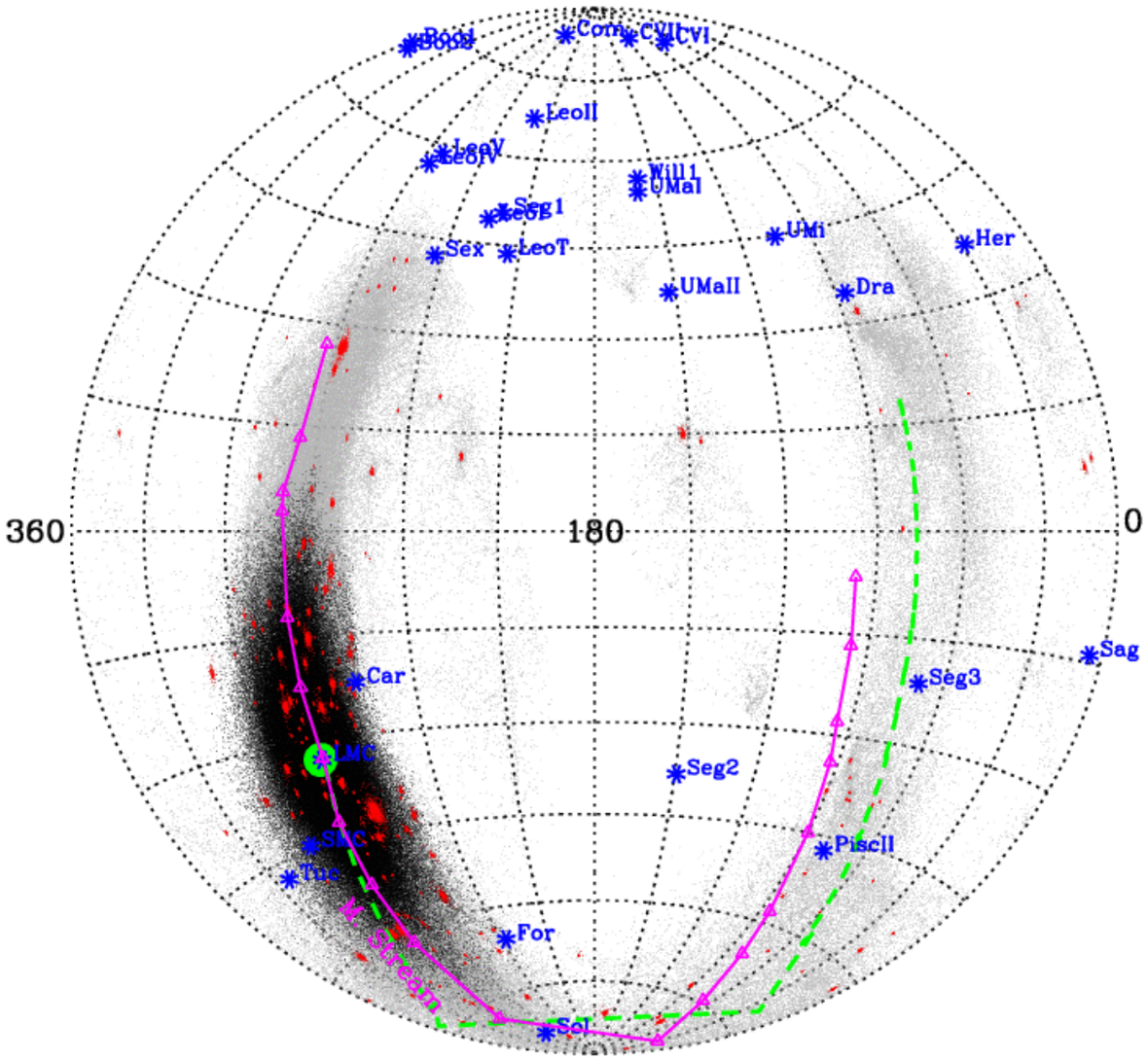
first pericenter (t_{1p})



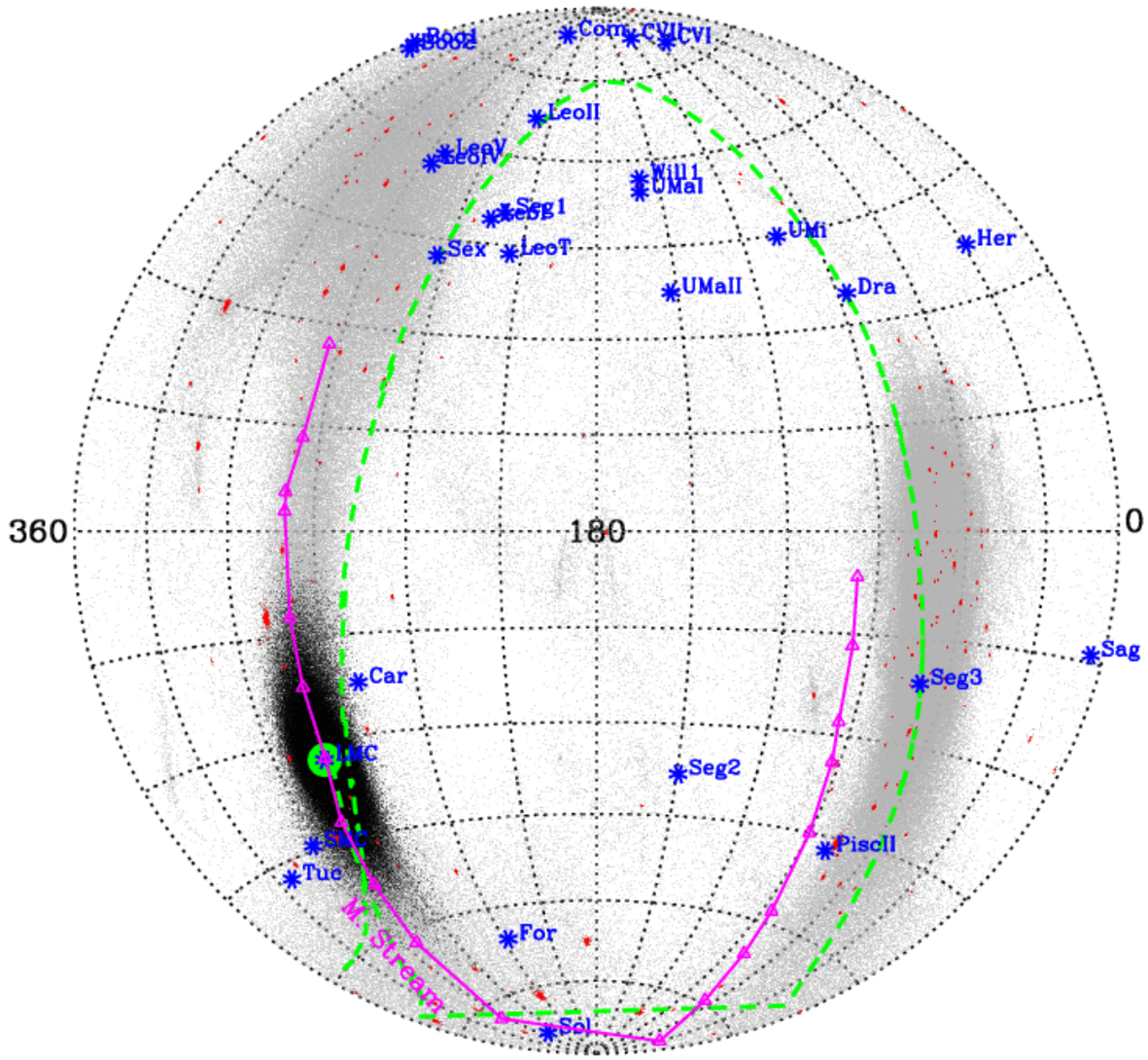
second pericenter (t_{2p})

(Sales et al. 2011)

The satellite companions of the LMC

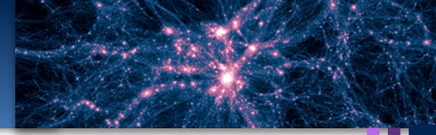


first pericenter (t_{1p})

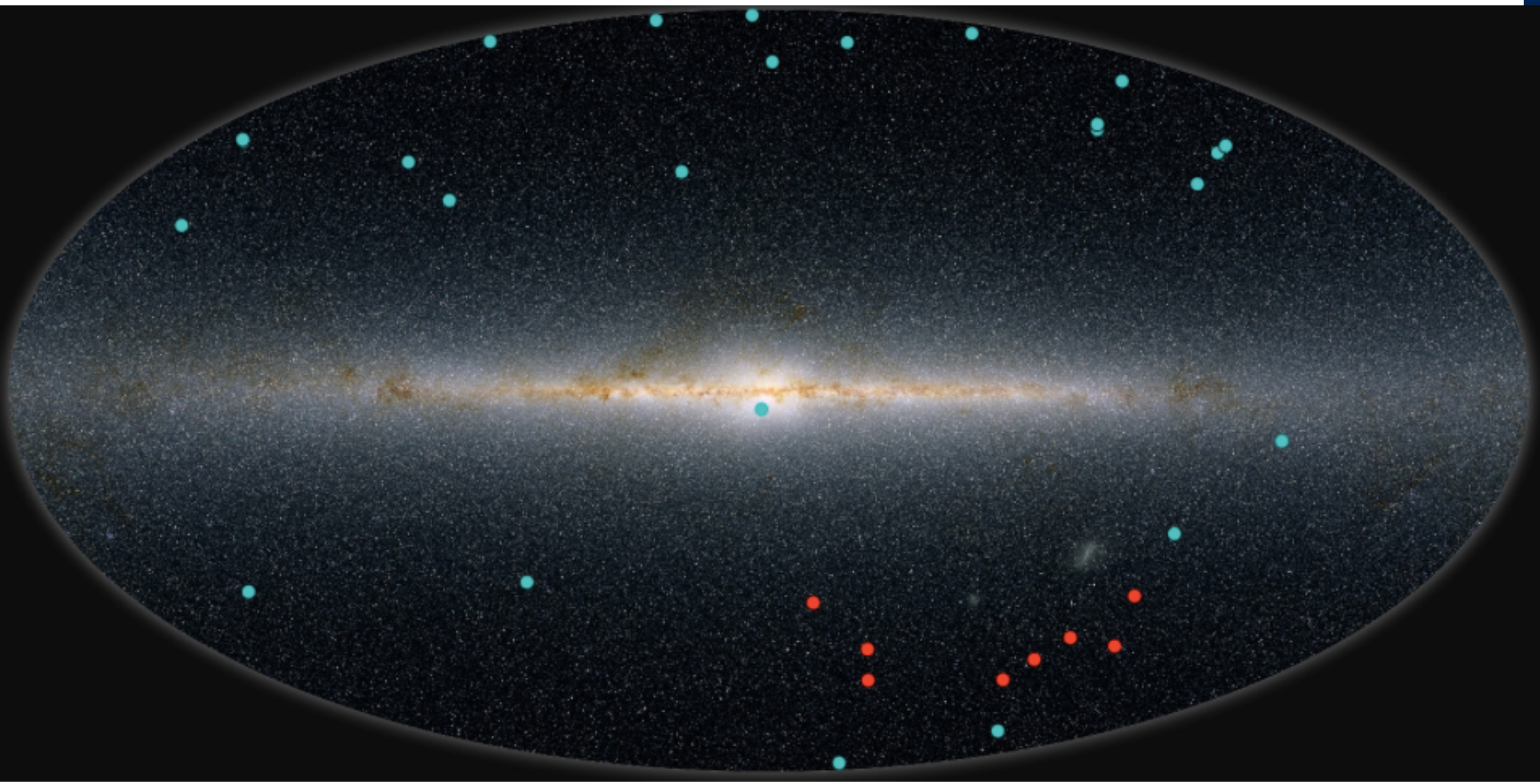


second pericenter (t_{2p})

better data become available. The dearth of satellites clearly associated with the Clouds might be solved by wide-field imaging surveys that target its surroundings, a region that may prove a fertile hunting ground for faint, previously unnoticed MW satellites. *(Sales et al. 2011)*



New dwarfs in the Dark Energy Survey (DES)



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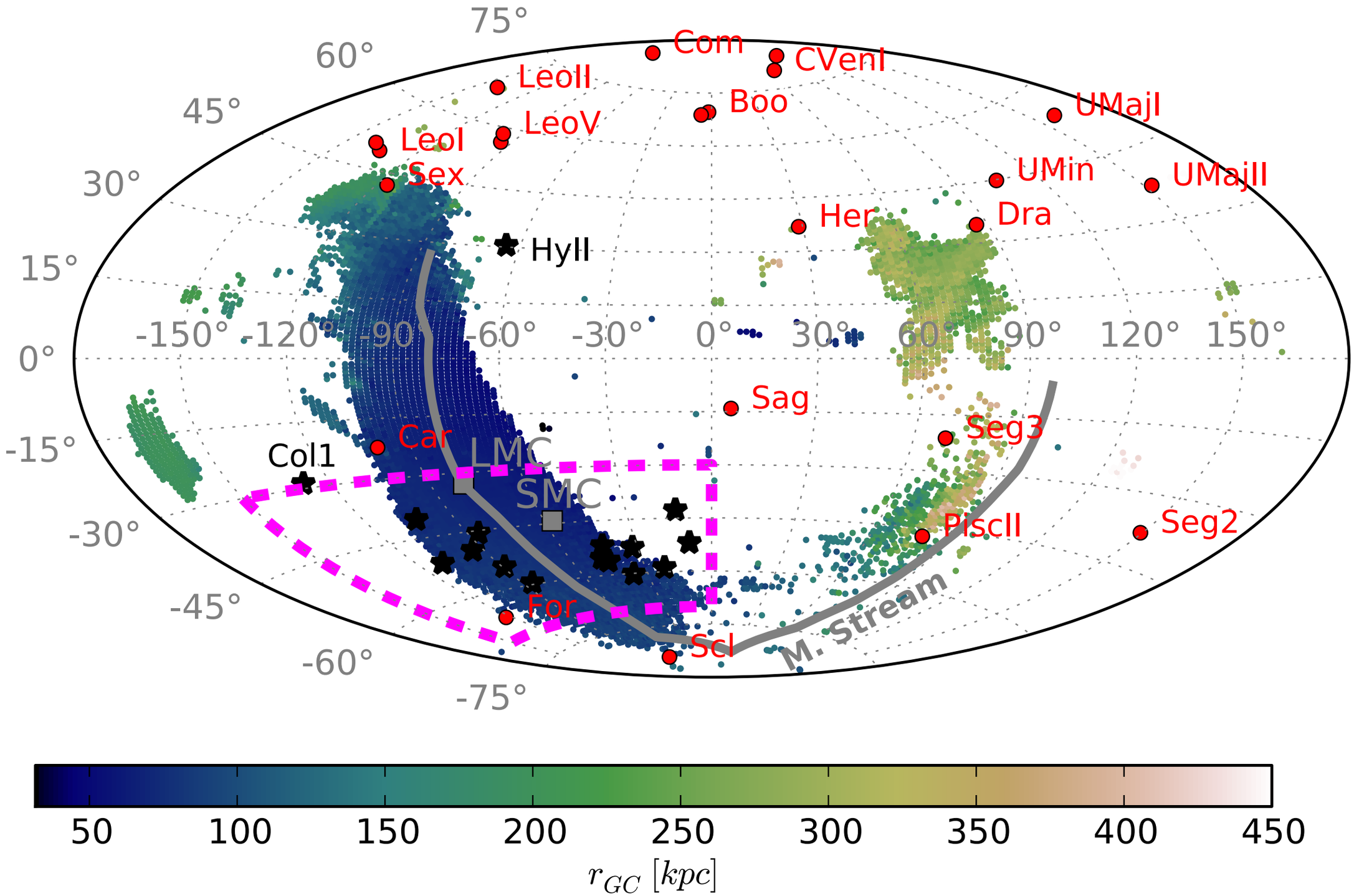
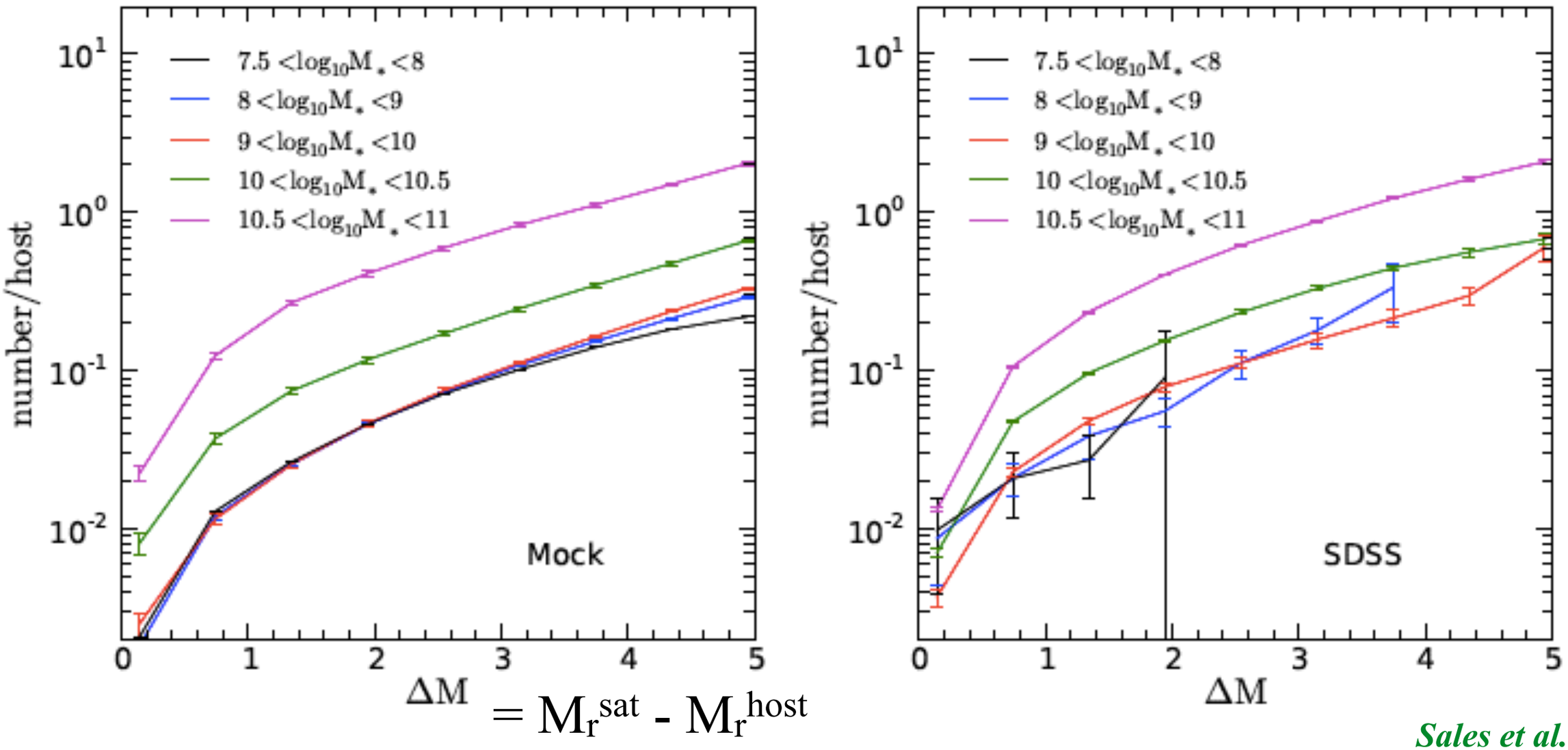
Distribution on the sky of the "LMC-system”



(Sales et al., in-prep)

Faint satellites:
The need to push beyond Local Group



Sales et al. 2013

First tests seem encouraging, but we need to peer deeper to identify fainter dwarf companions

Faint satellites:
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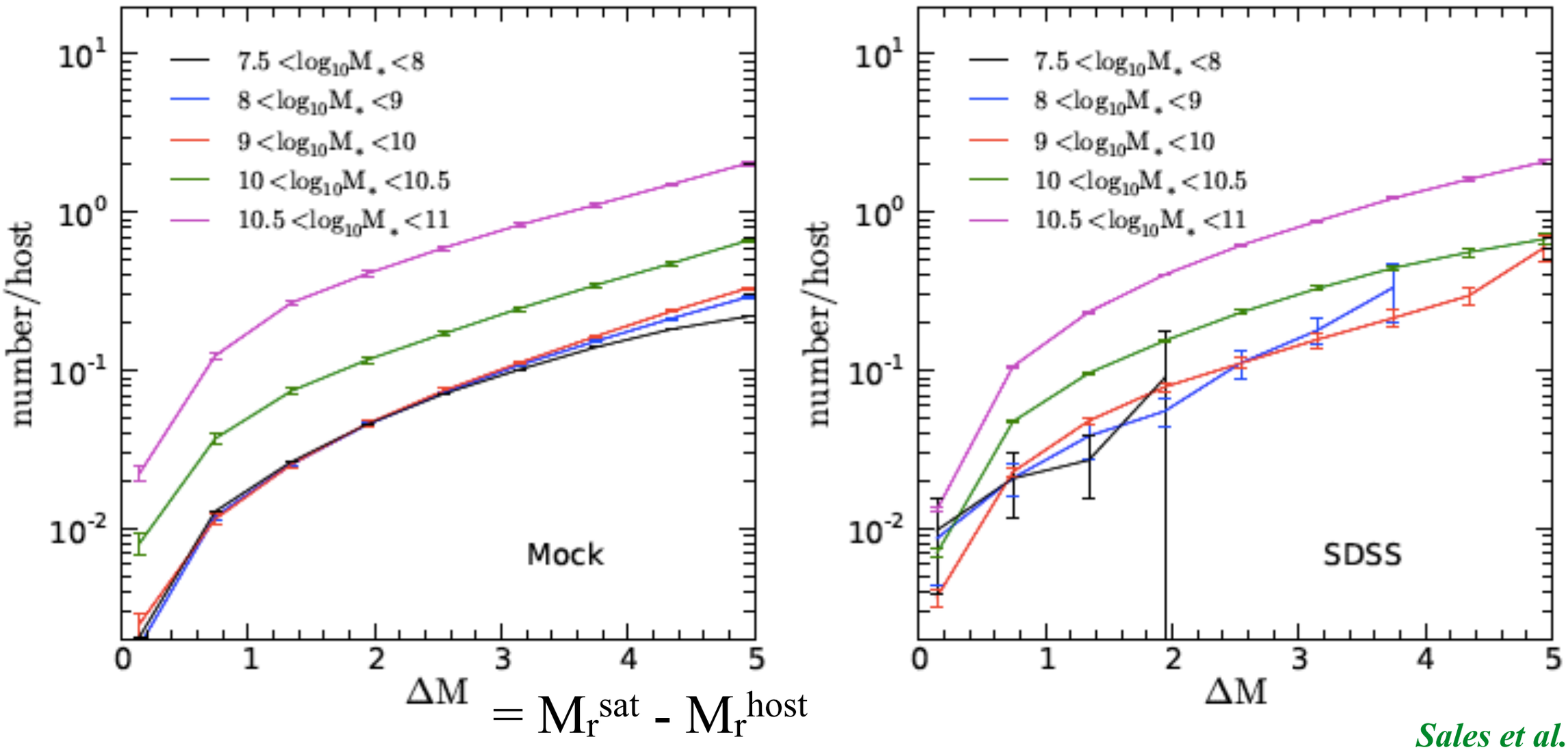


Sales et al. 2013

First tests seem encouraging, but we need to peer deeper to identify fainter dwarf companions

WFIRST!

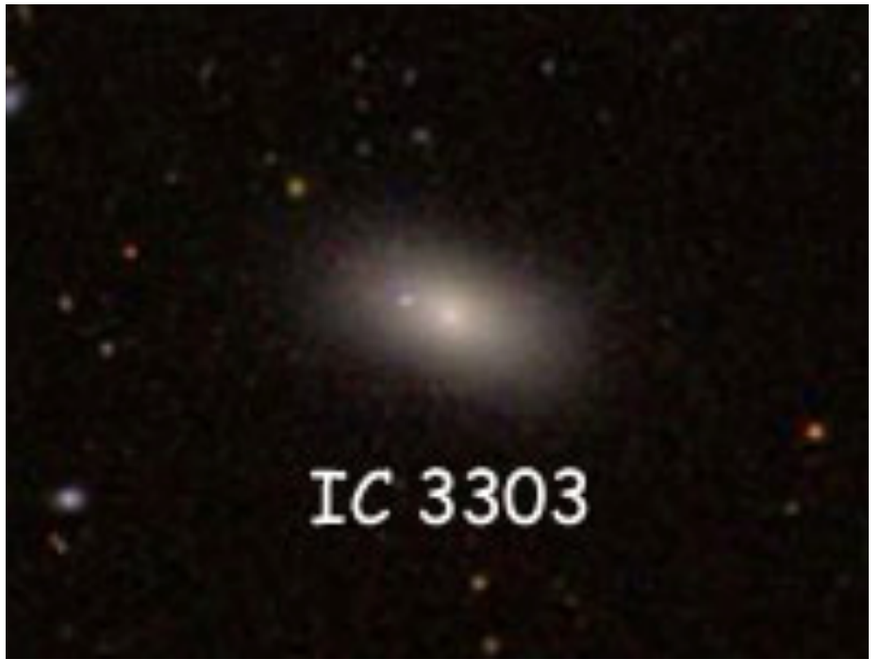
The assembly of dwarf galaxies in clusters

Virgo Cluster

Dwarf Galaxies:

A rather heterogeneous class of objects

Clusters



dE

Field

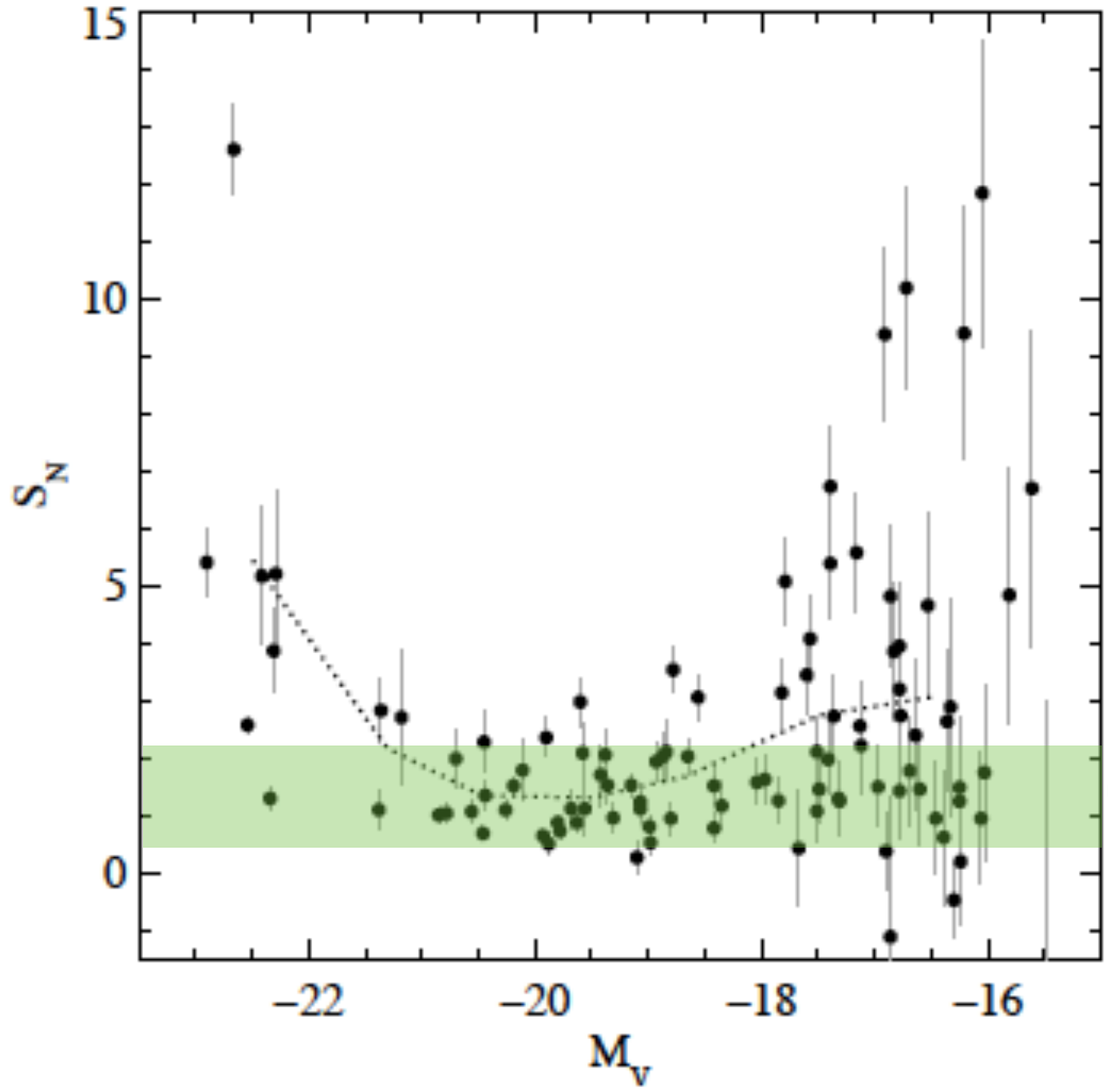
dIrr

progenitors?

But globular clusters (GC) numbers don't add up…

Number of GC per unit v-band galaxy luminosity

"specific frequency"



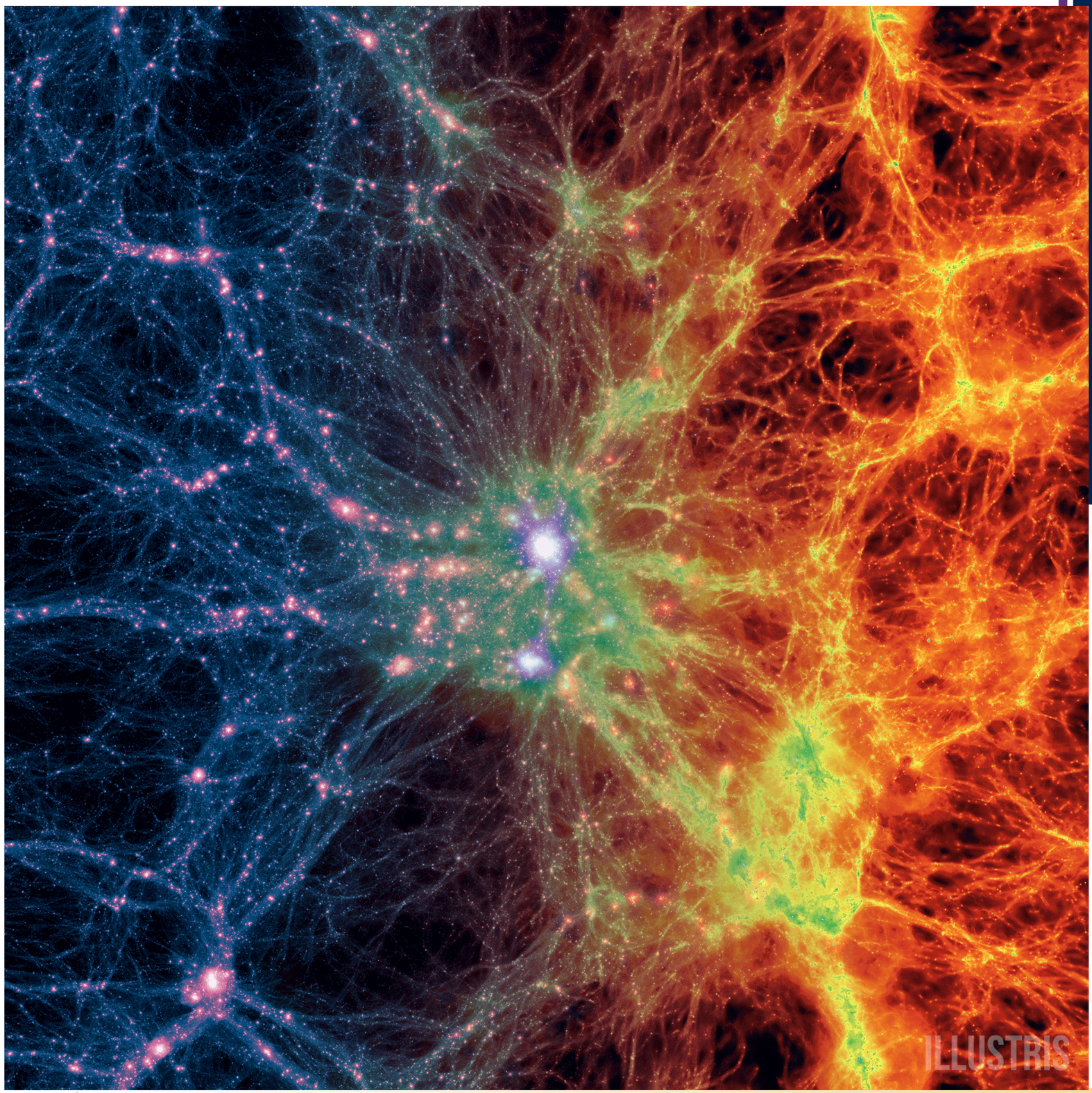
field spirals

(see also e.g., Durrell 1998, Miller & Lotz 2007, others)

The Illustris Simulation

- Cosmological/Hydrodynamical
- Run with AREPO
- L_{box} ~100 Mpc
- m_p ~1.3 x 10^6 M_{sun} (baryons)

~20000 galaxies at z=0



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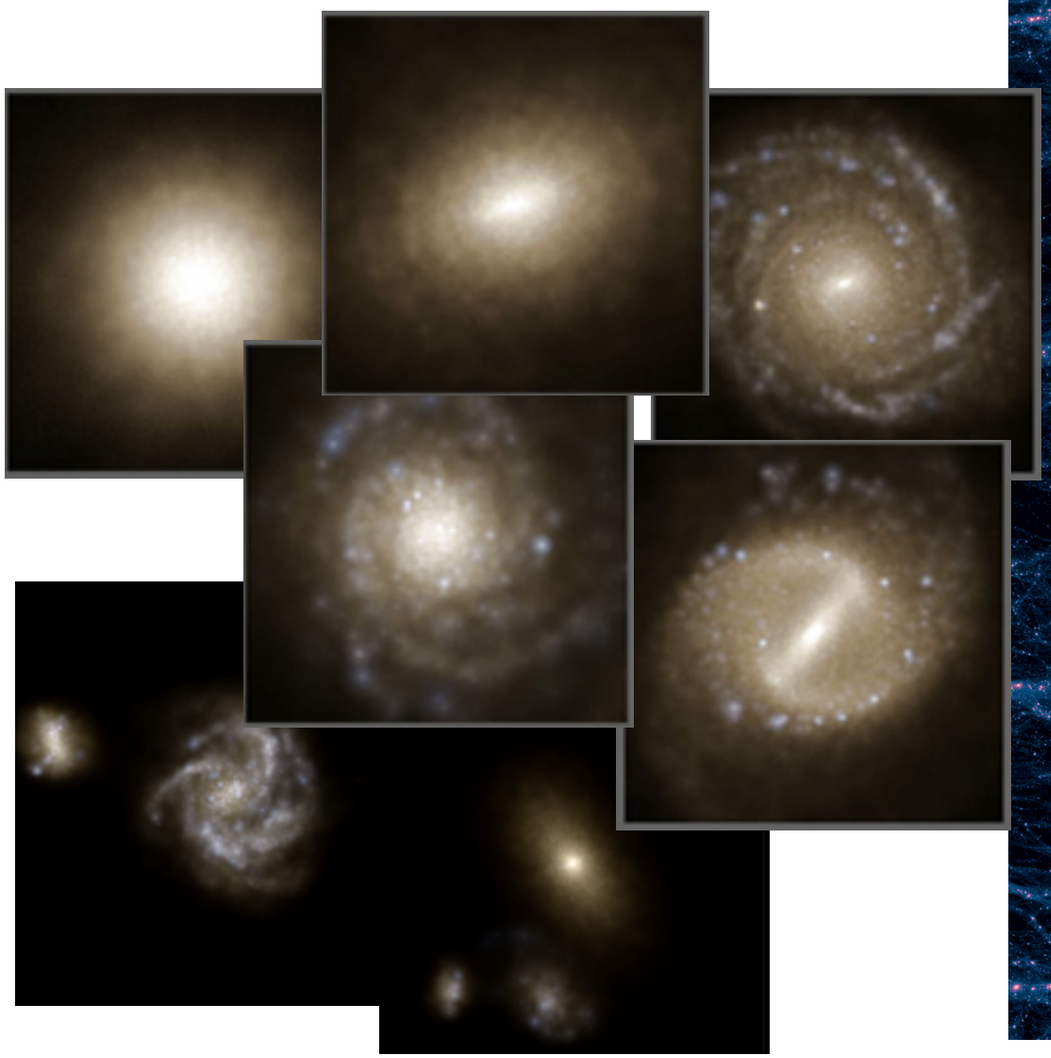
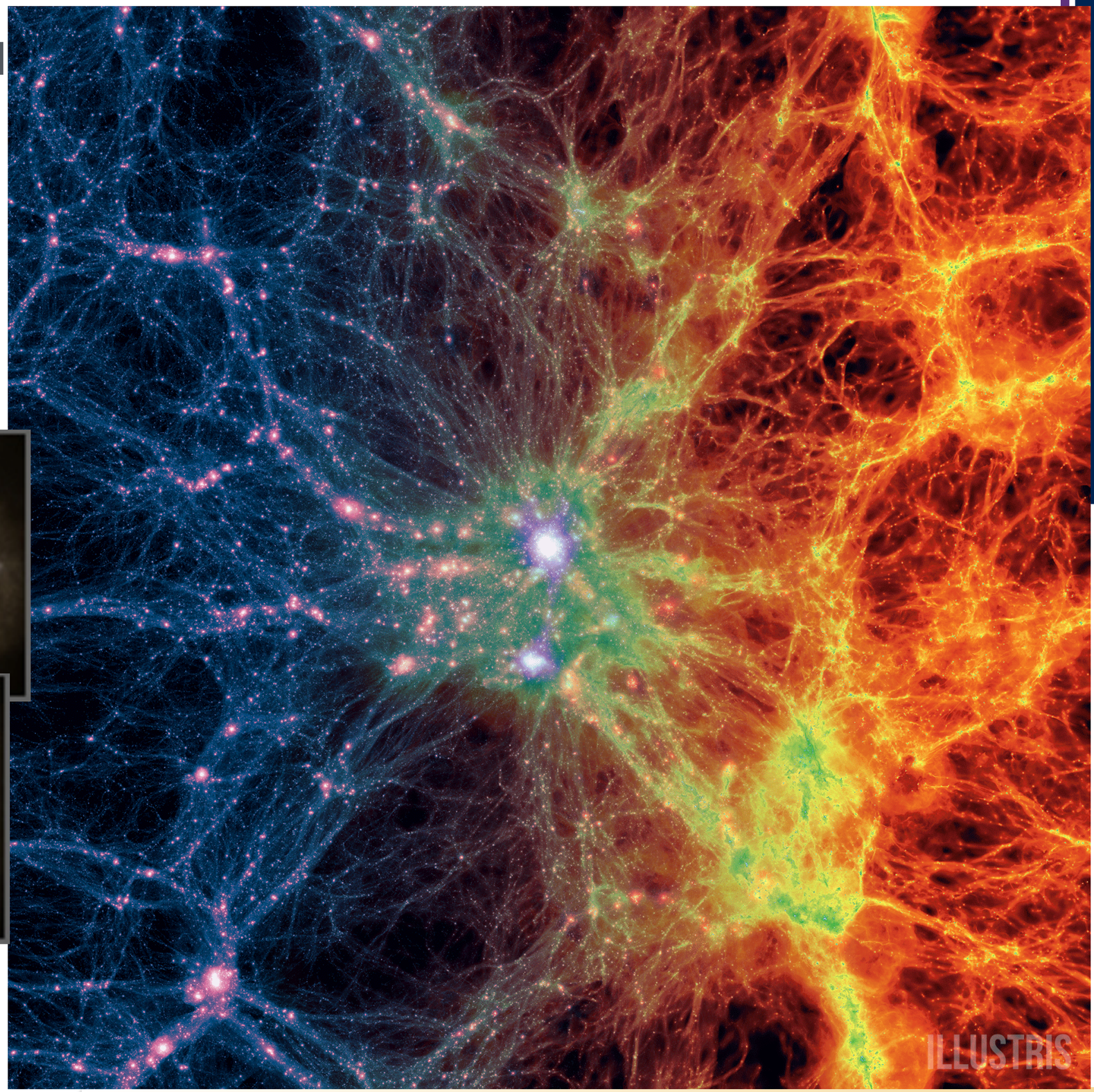
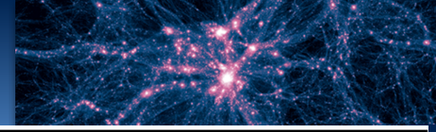
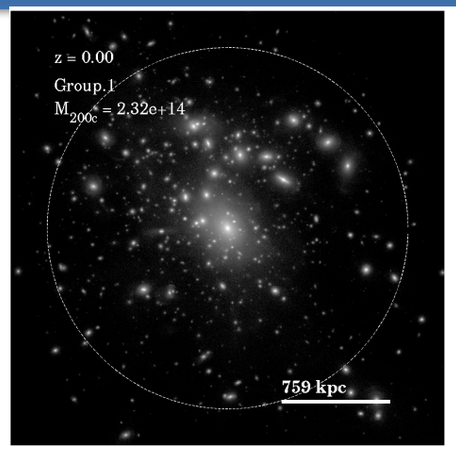


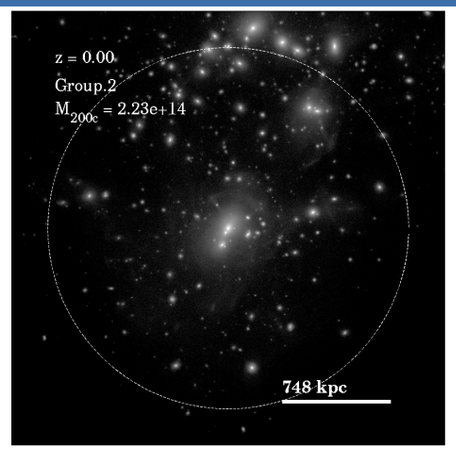


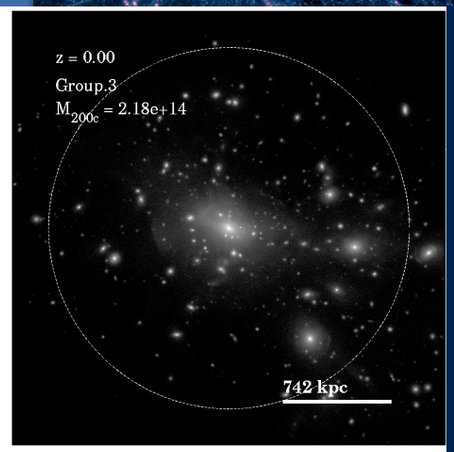
Massive galaxy clusters in Illustris

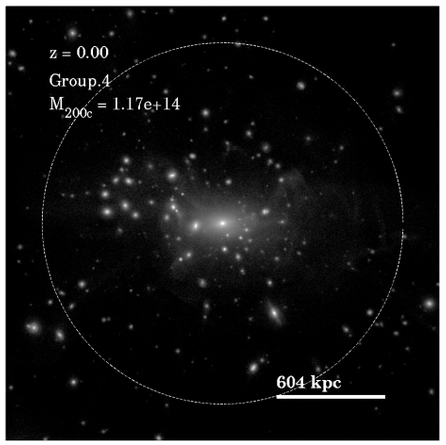
$M_{vir} > 5x10^{13} M_{sun}$

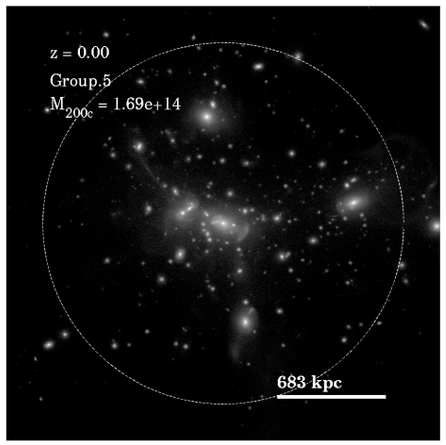


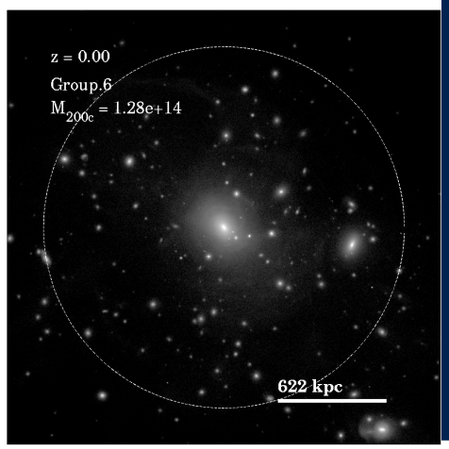


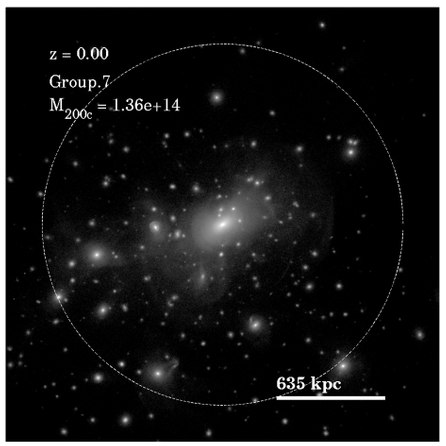


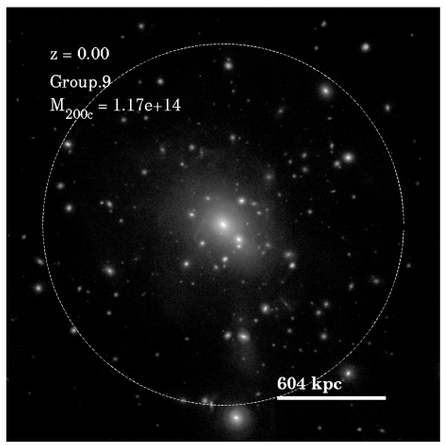


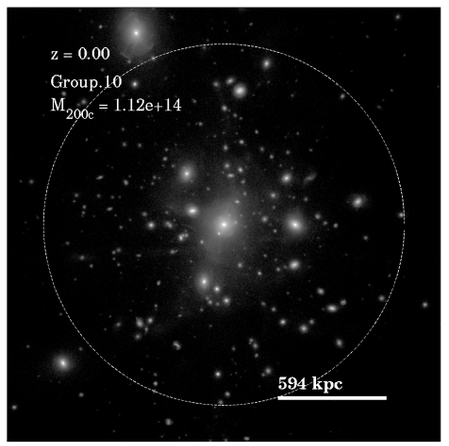


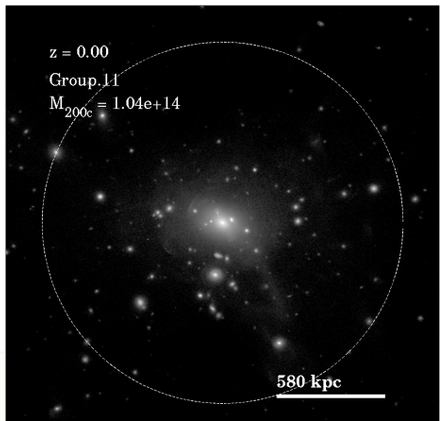


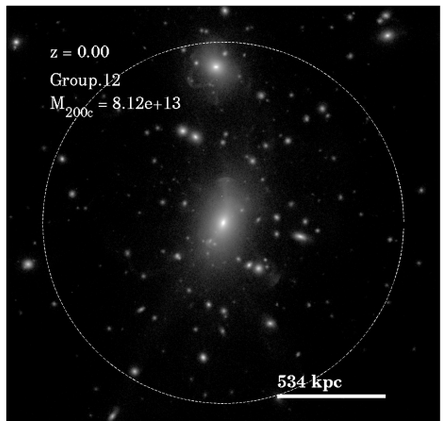


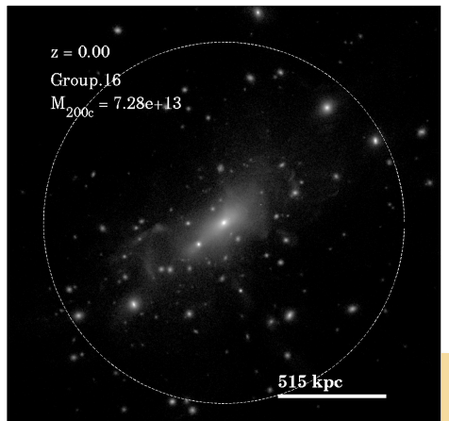












(Mistani, LVS, et al., MNRAS *in-press)*

Massive galaxy clusters in Illustris

$M_{vir} > 5x10^{13}\ M_{sun}$

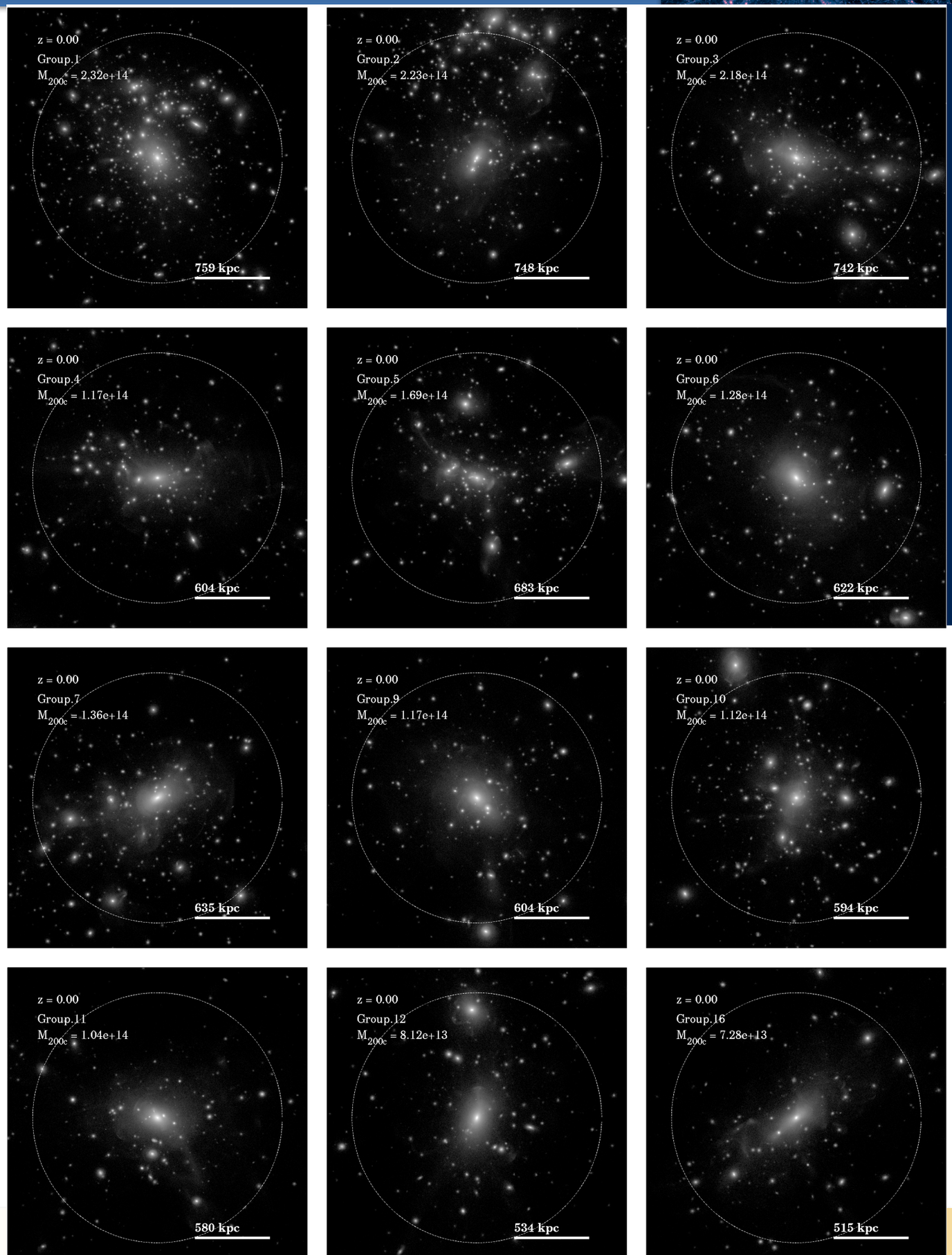
Dwarfs:

$M_{*}=[3x10^{8} - 10^{10}]\ M_{sun}$

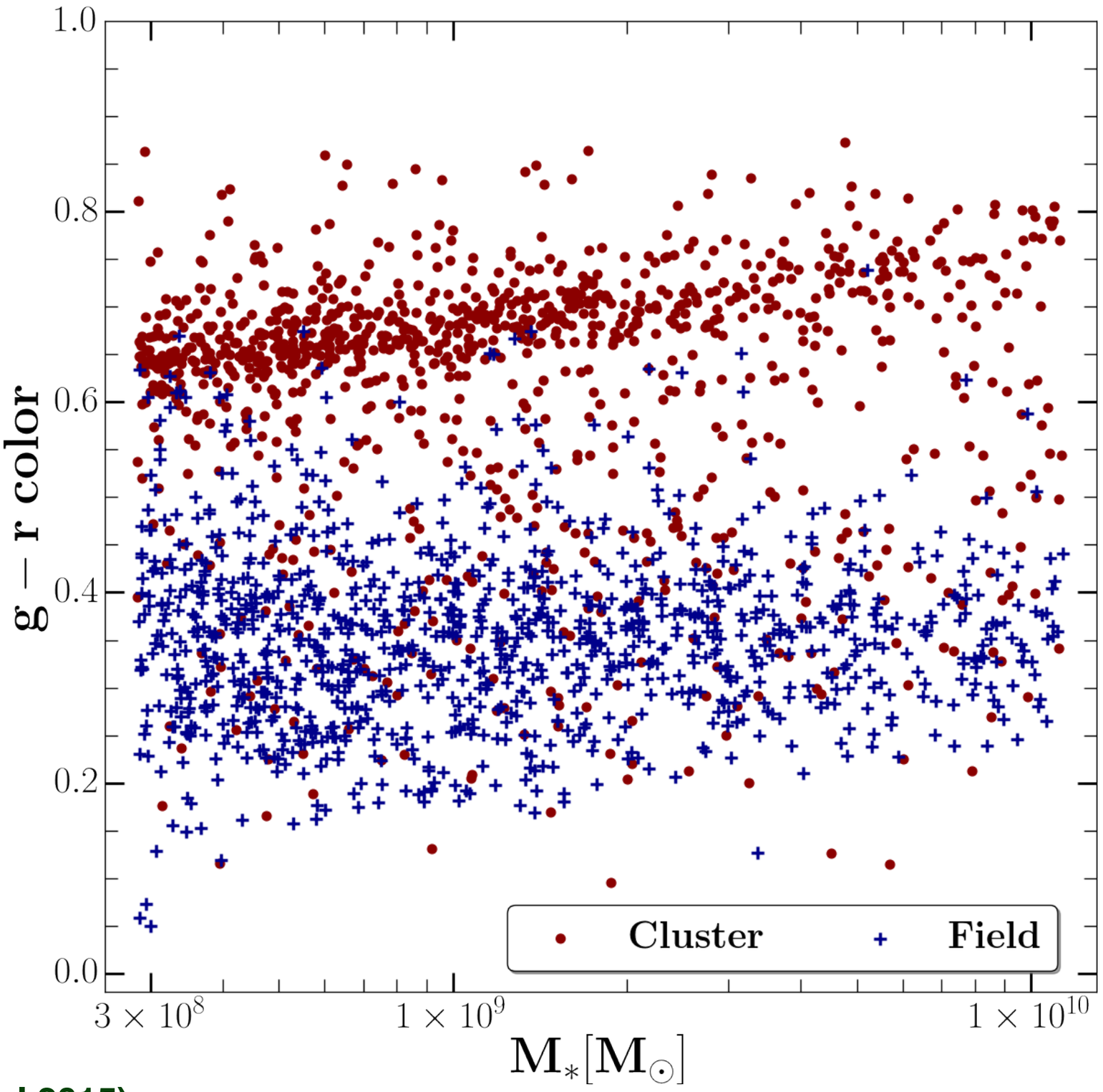
~1100 dwarfs in clusters

—> selected comparison ~1100 field dwarfs

(Mistani, LVS, et al., MNRAS *in-press)*

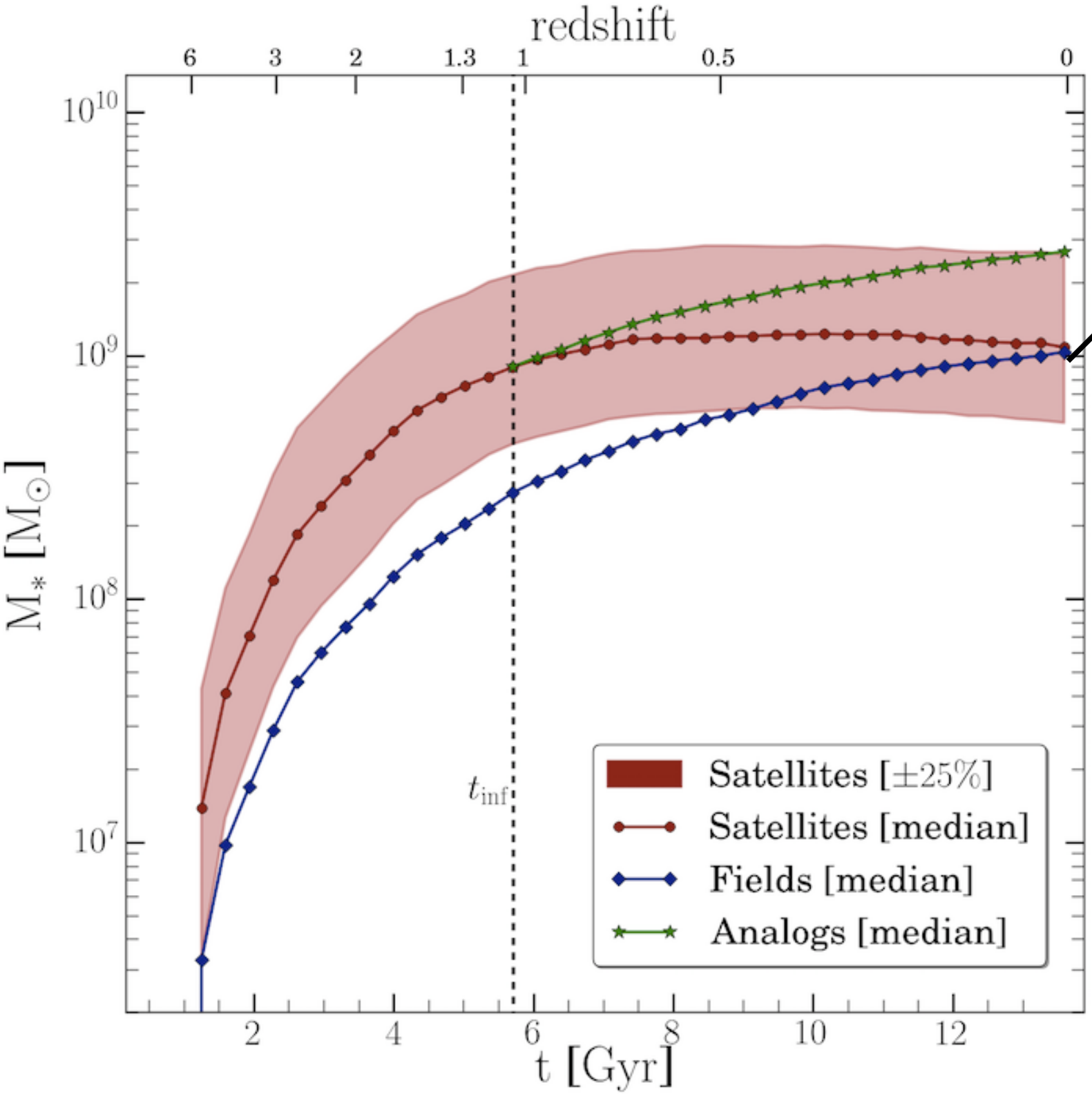


The colors of cluster and field dwarfs in Illustris



(See also Sales et al 2015)

1) The mass assembly of cluster and field dwarfs



Dwarfs in clusters were more massive than field dwarfs at all times

(Mistani et al., MNRAS *in-press)*

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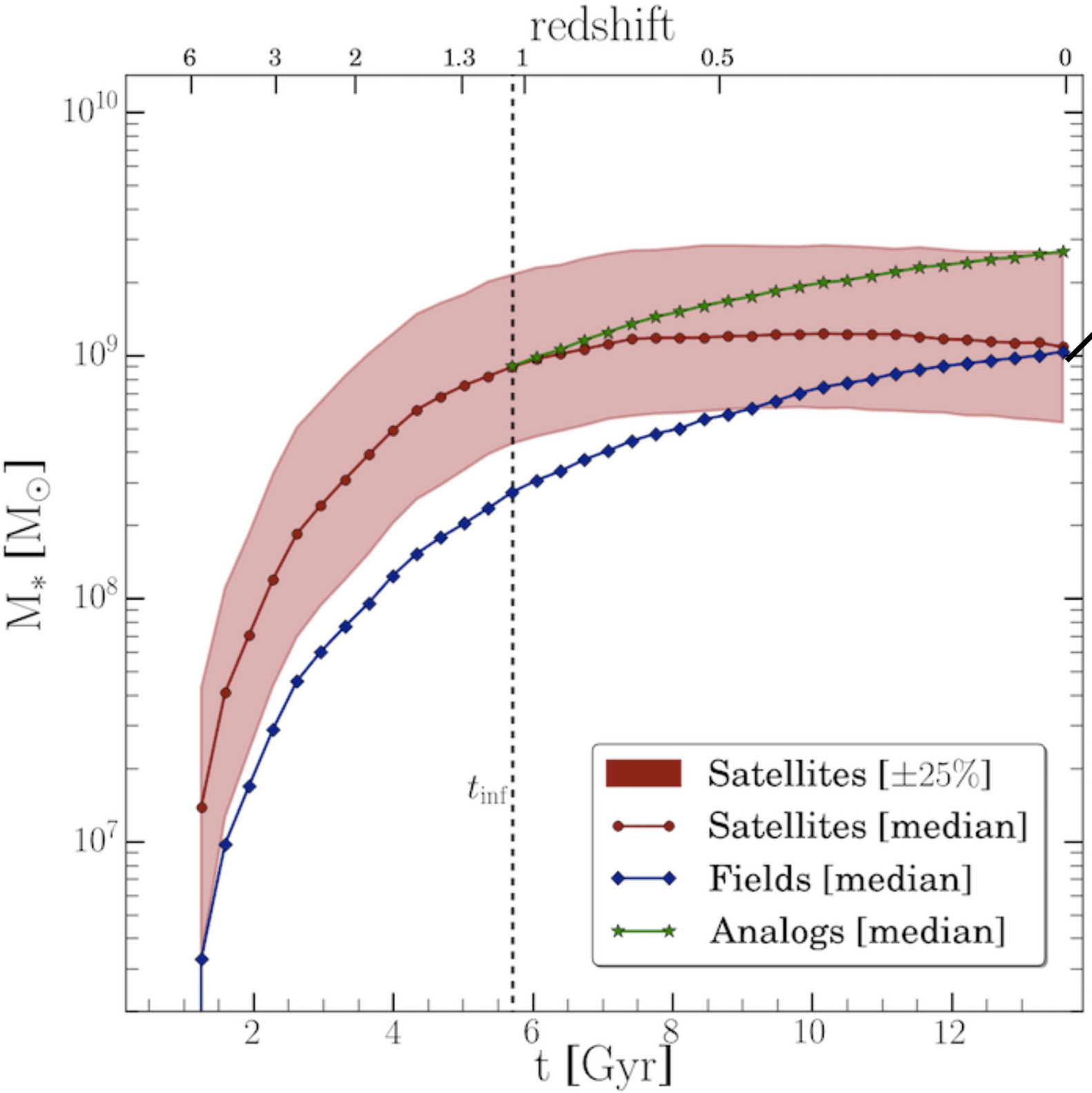
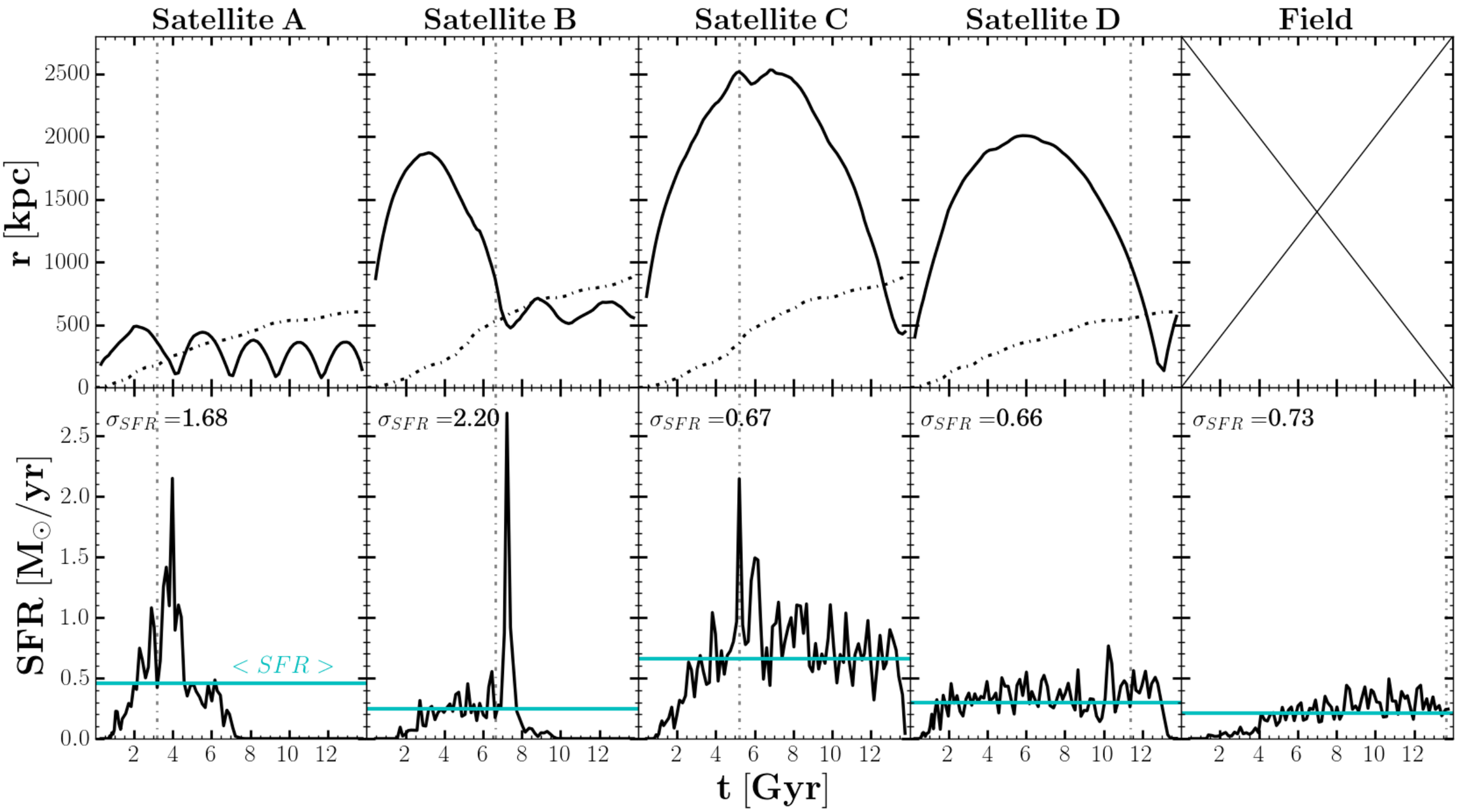


Dwarfs in clusters were more massive than field dwarfs at all times

Higher SFR

(Mistani et al., MNRAS *in-press)*

2) The star formation history of cluster and field dwarfs



Satellites tend to have starbursts associated to virial radius crossing and/or pericenters

(Mistani et al., MNRAS in-press)

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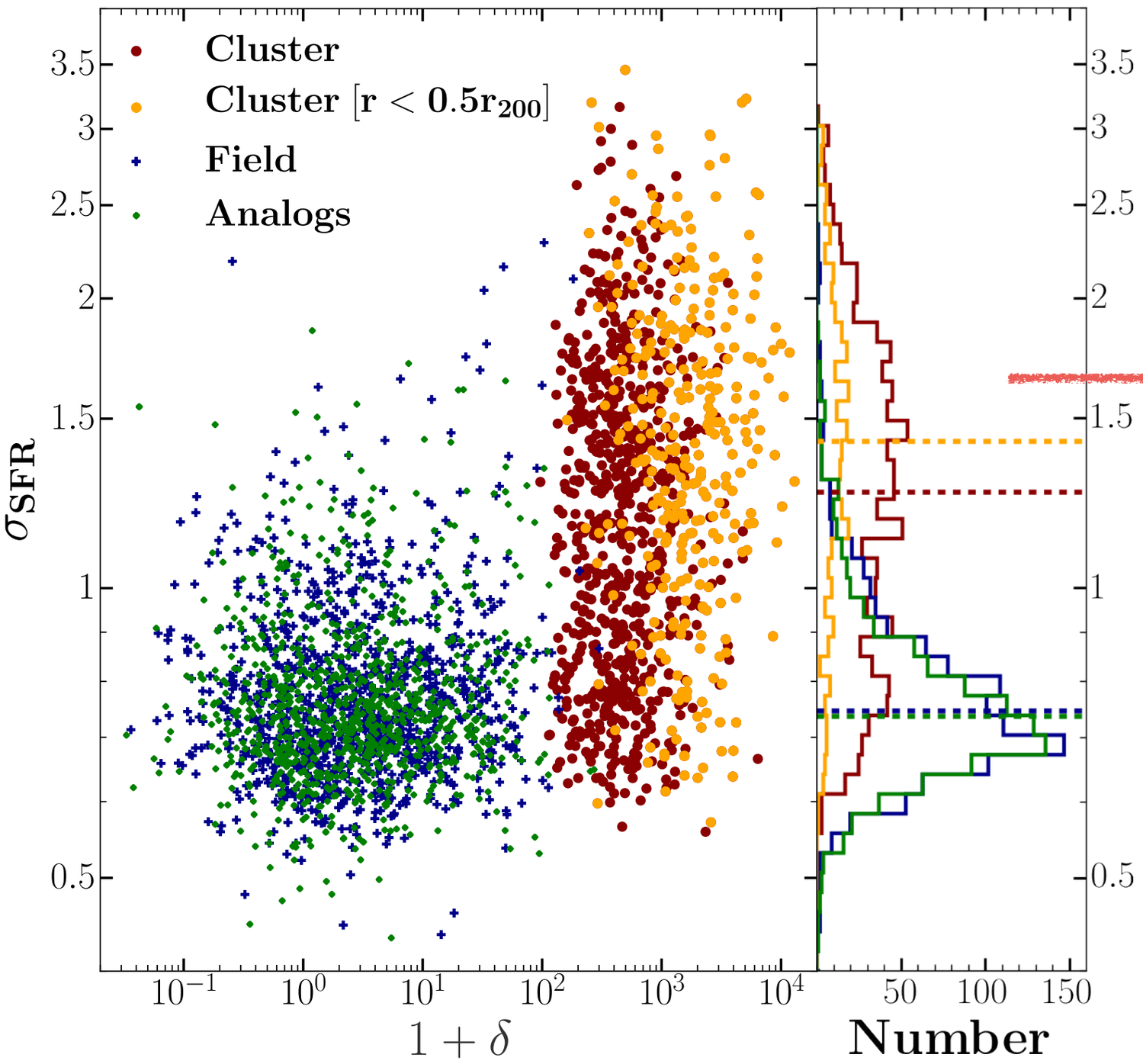

Starbursts

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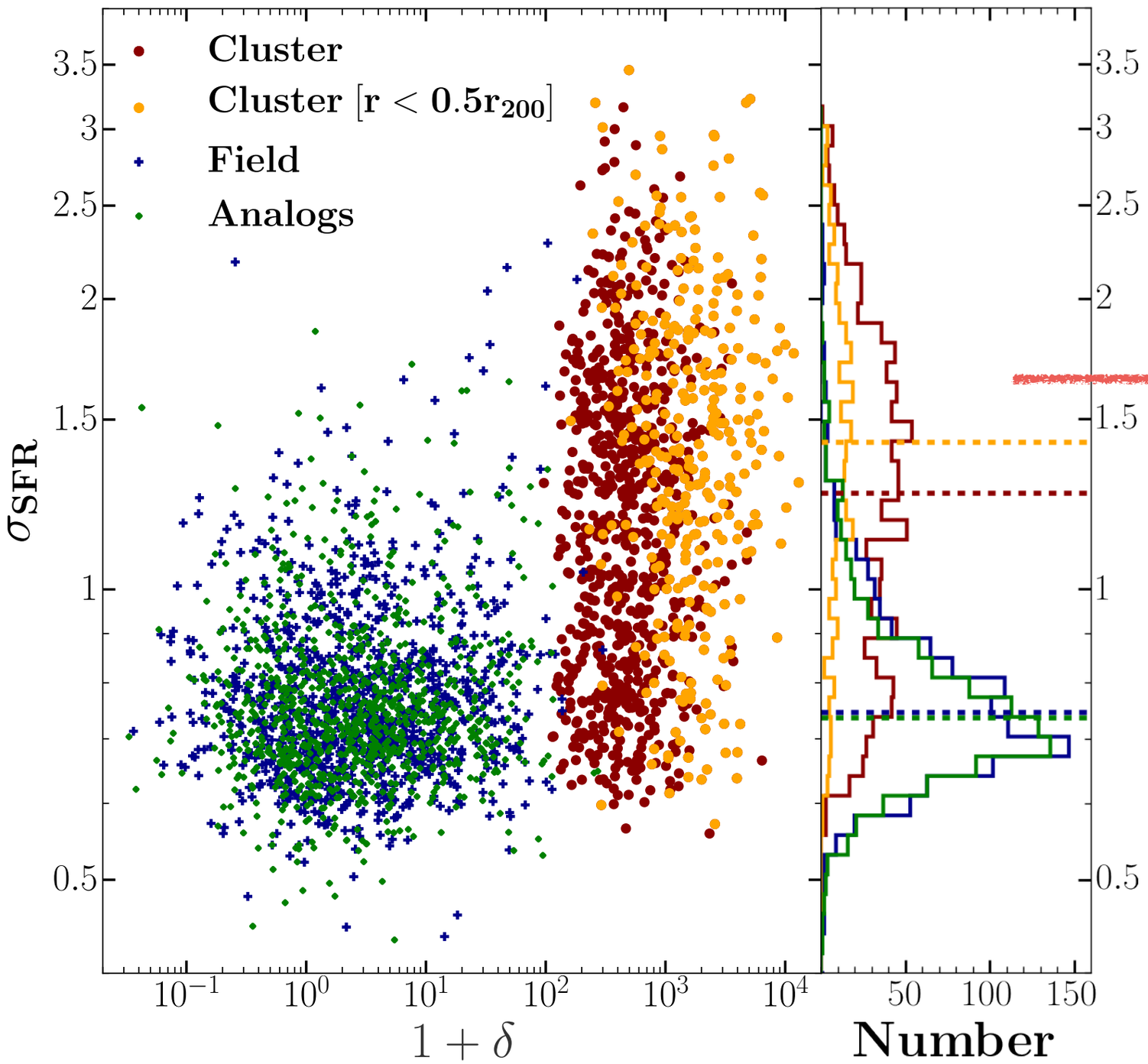

Starbursts

Consequences for the GC population?

(Mistani et al., MNRAS in-press)

What can we say about the specific GC frequency?

Post-processing model for GC formation & tidal evolution:

1) Compute the mass in GCs
2) M_{GC} —> Number
3) Tagging of DM particles to evaluate stripping

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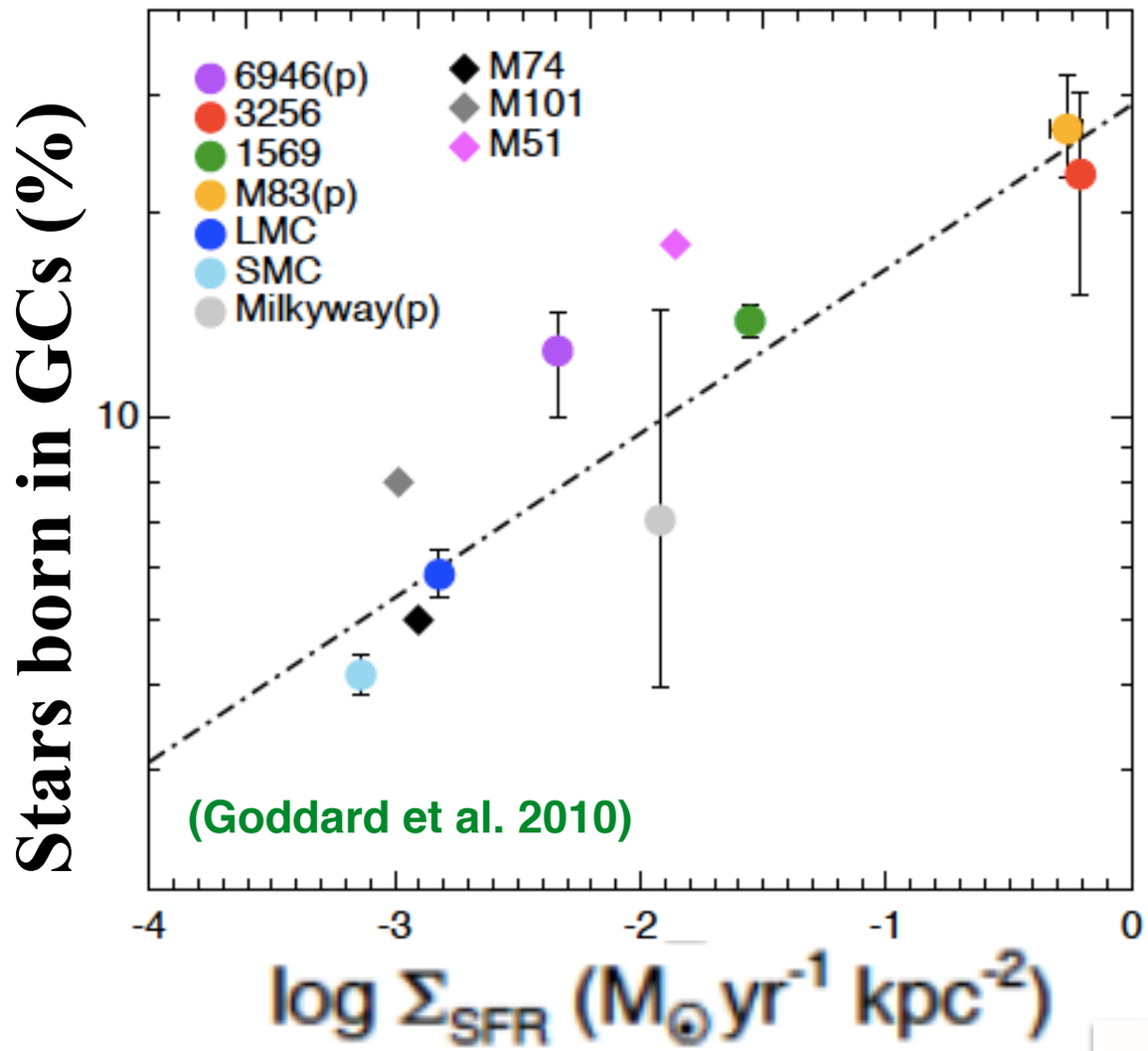
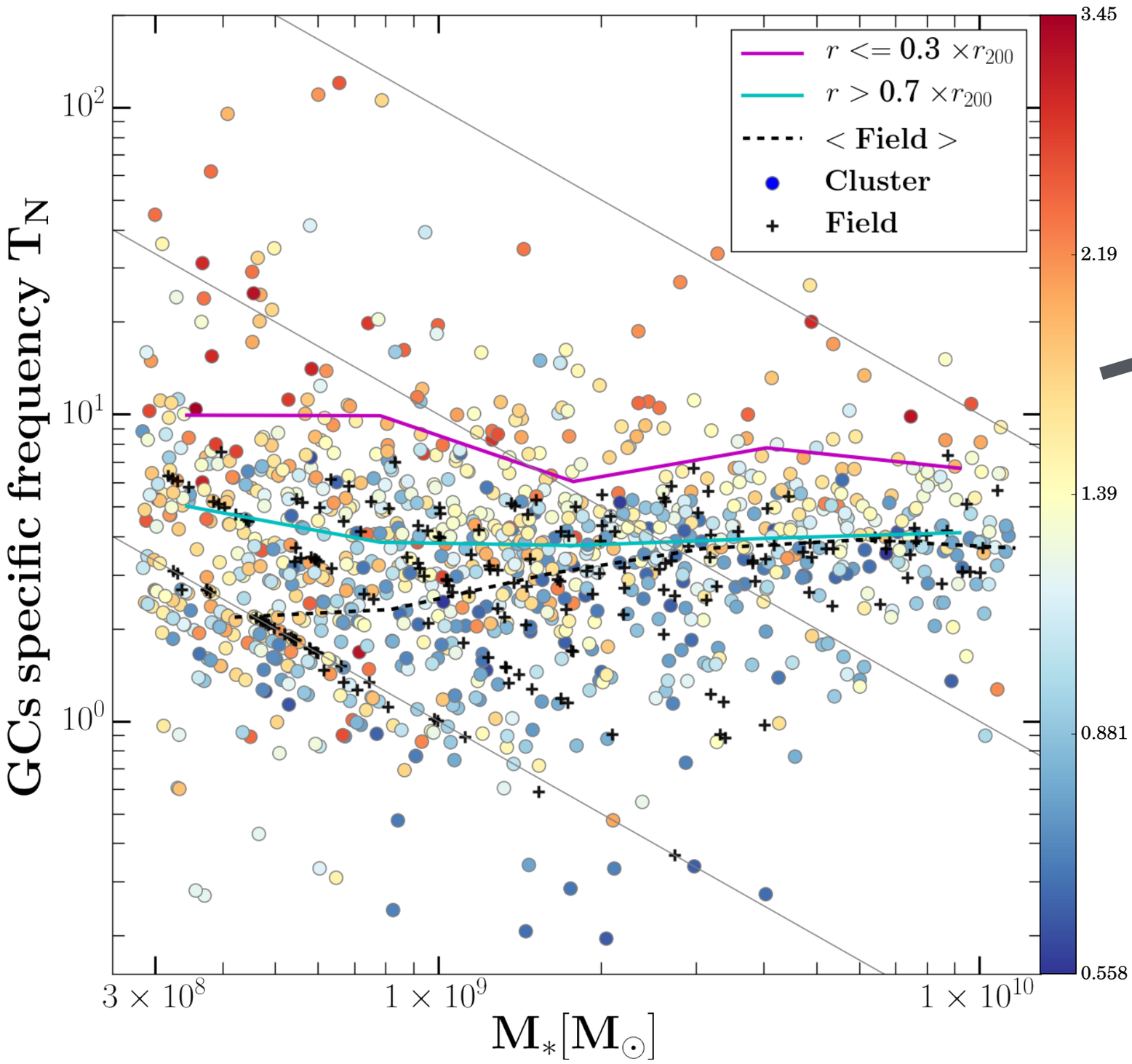


Observationally…

High SFR density ==> more efficient GC formation

3) GCs content in cluster and field dwarfs

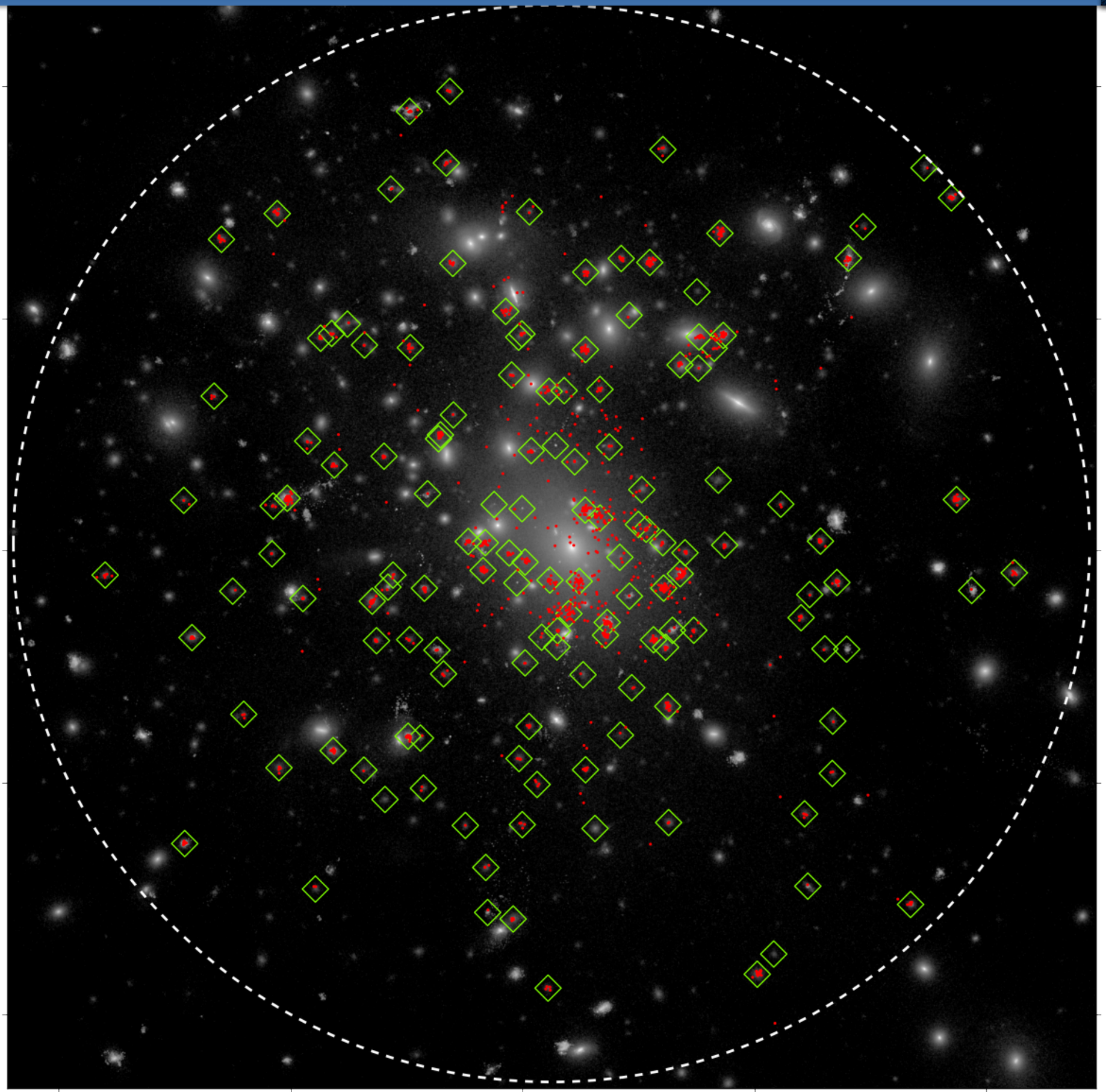


Cluster dwarfs have an excess of GCs in agreement with observations

Excess is largest for inner and more starbursty dwarfs

(Mistani et al., MNRAS *in-press)*

2. Dwarf Galaxies in Clusters



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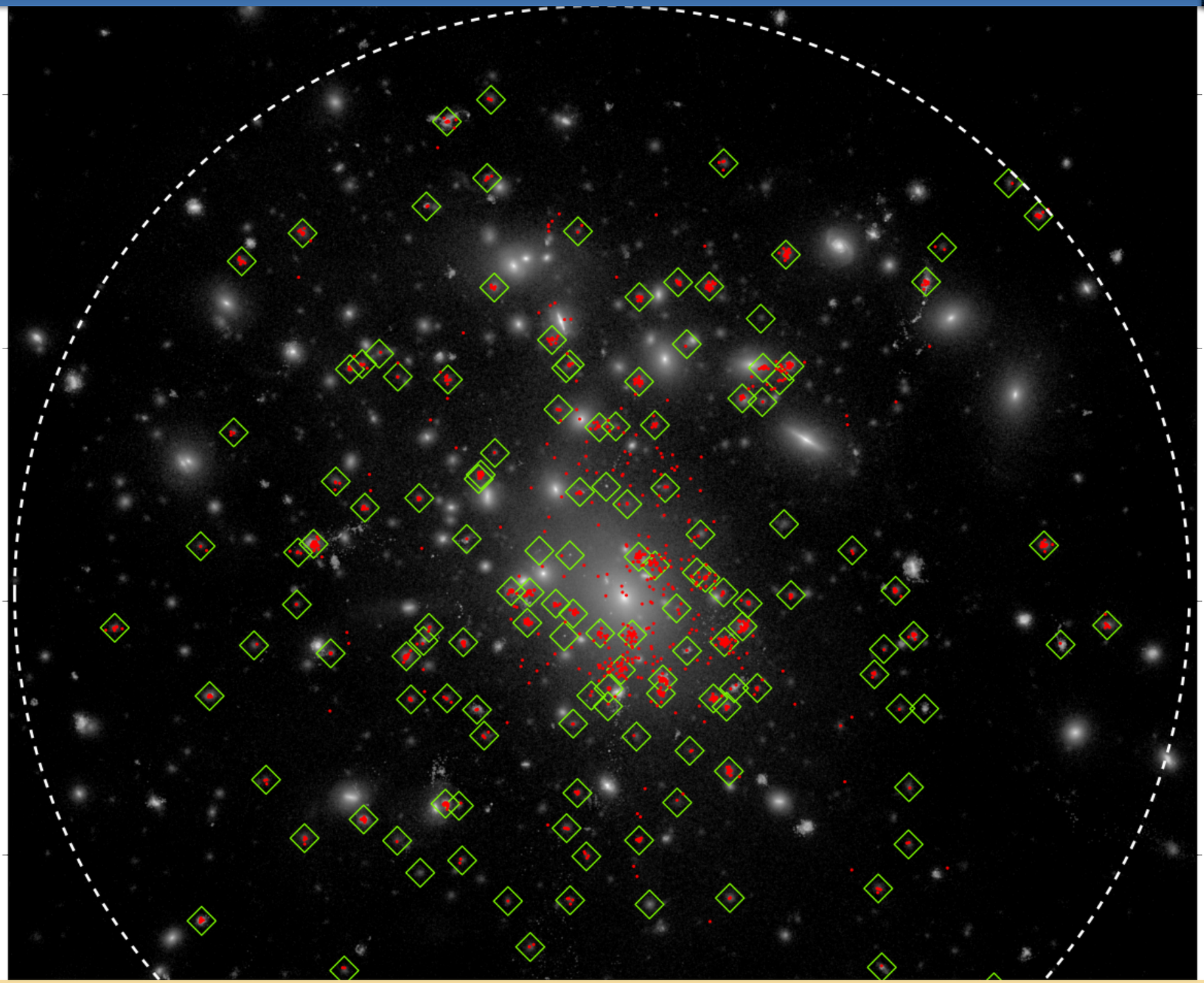
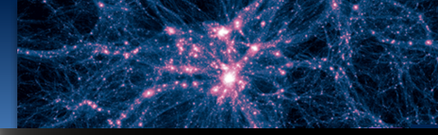


Using GCs as tracers, we can hope to get information about the DM distribution in cluster dwafs

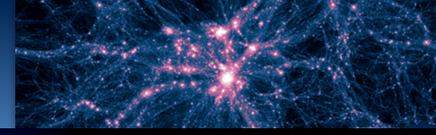
What about fainter dwarfs?

The APOSTLE simulations



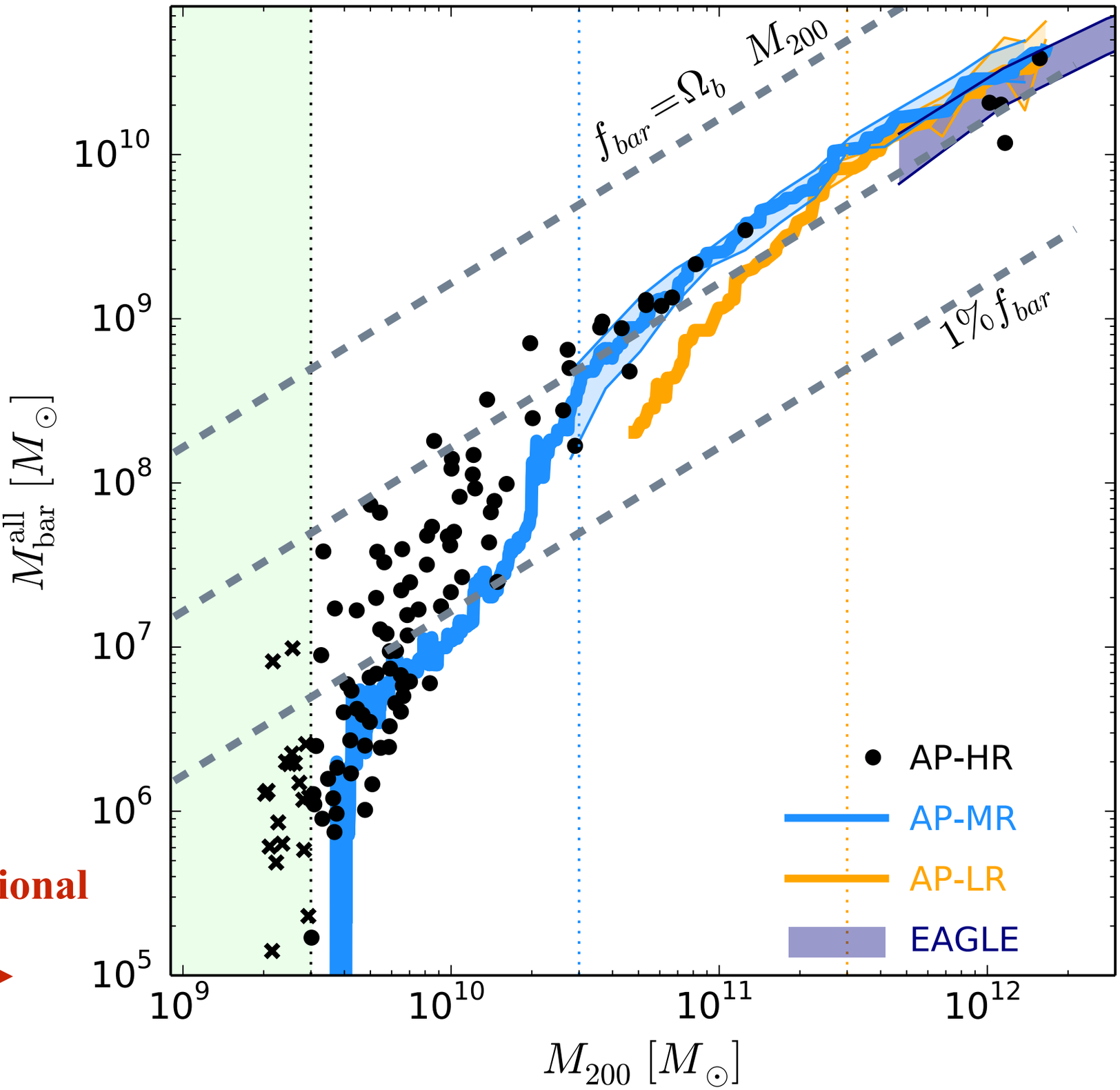
Credits: A. Fattahi

The APOSTLE simulations



Credits: A. Fattahi

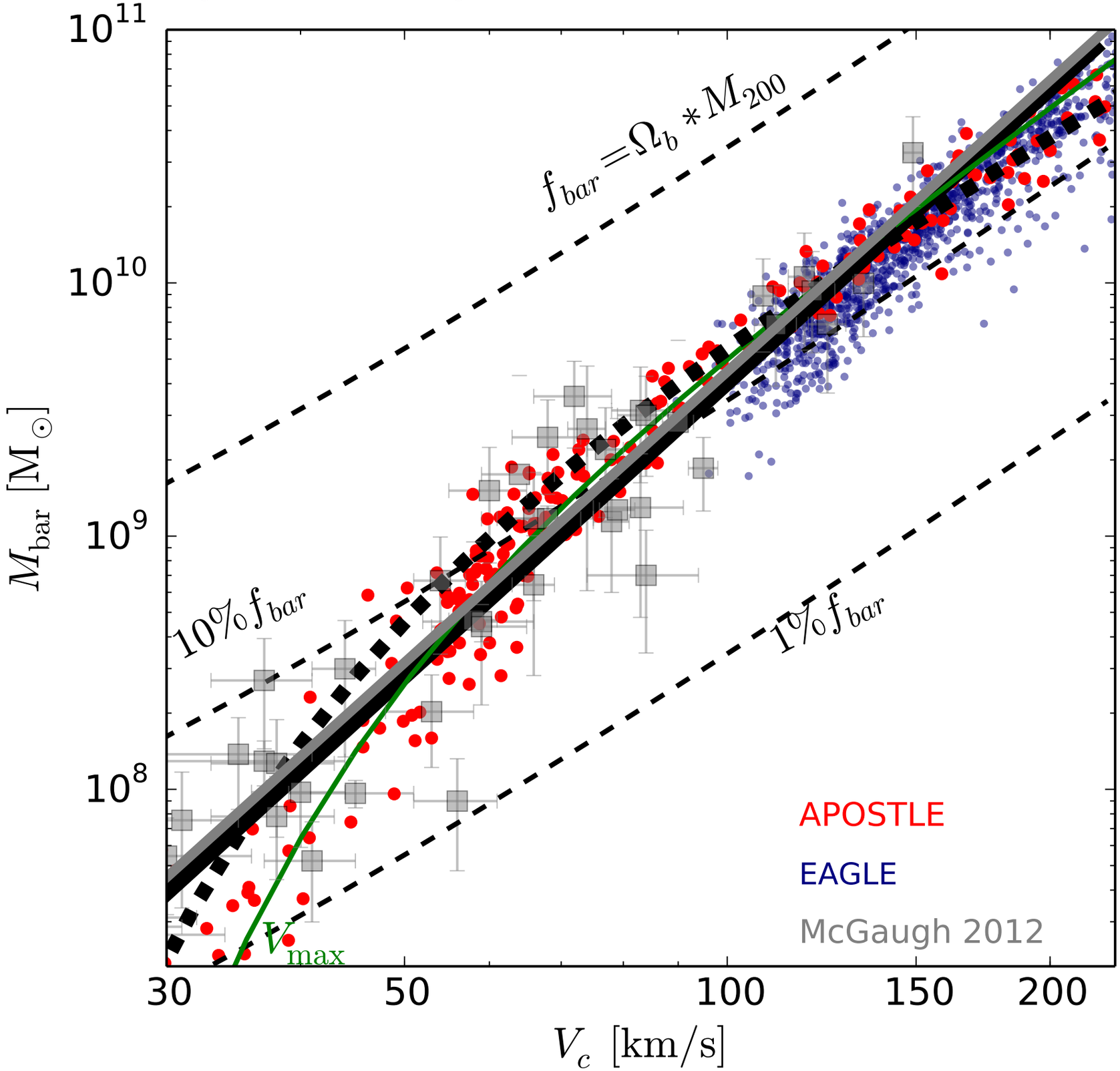
Predicting the M_{halo} - $M_{baryons}$ relation for dwarfs



But no observational data!

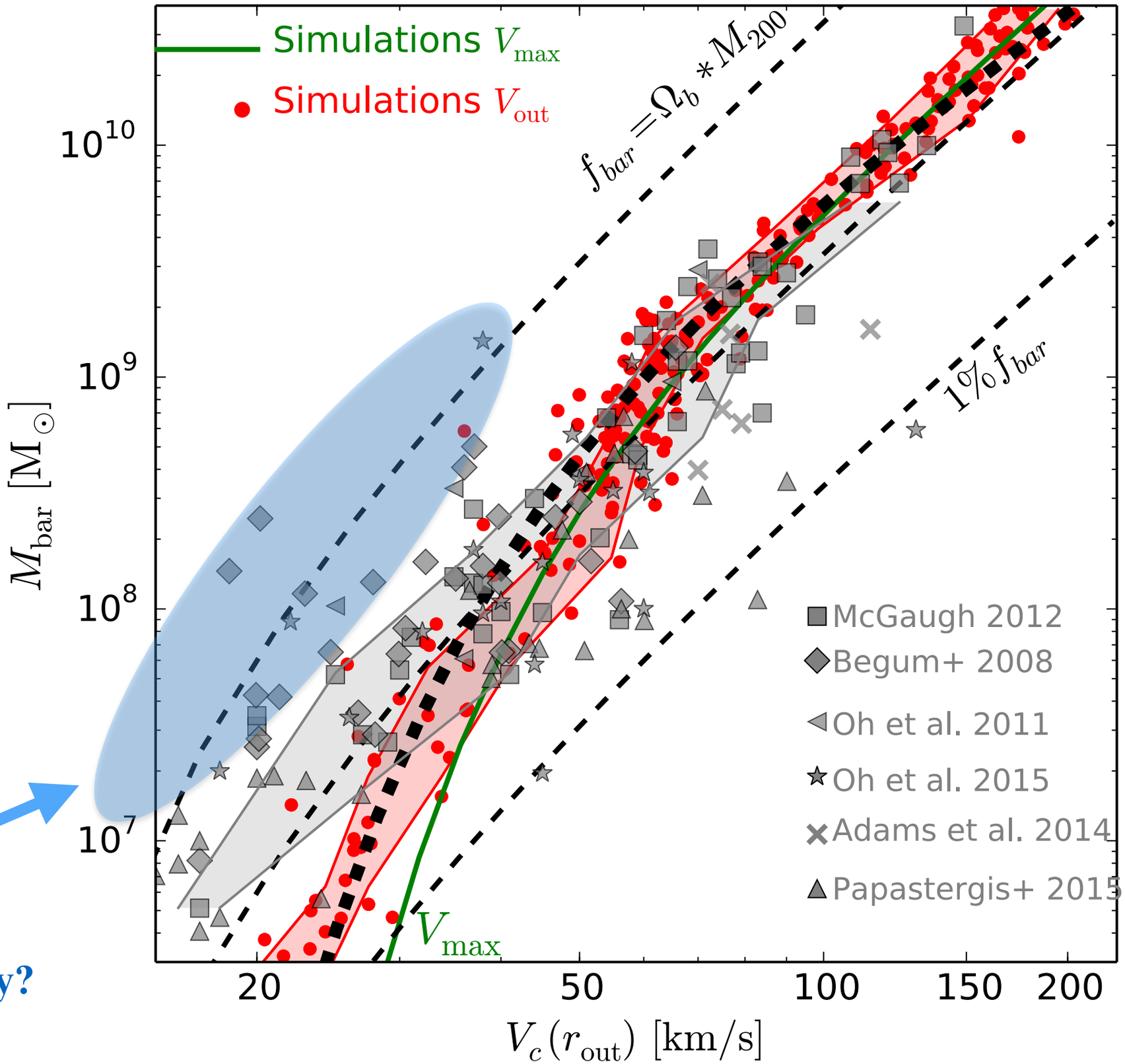
(Sales et al., submitted)

The Baryonic Tully-Fisher relation as constrain



(Sales et al., submitted)

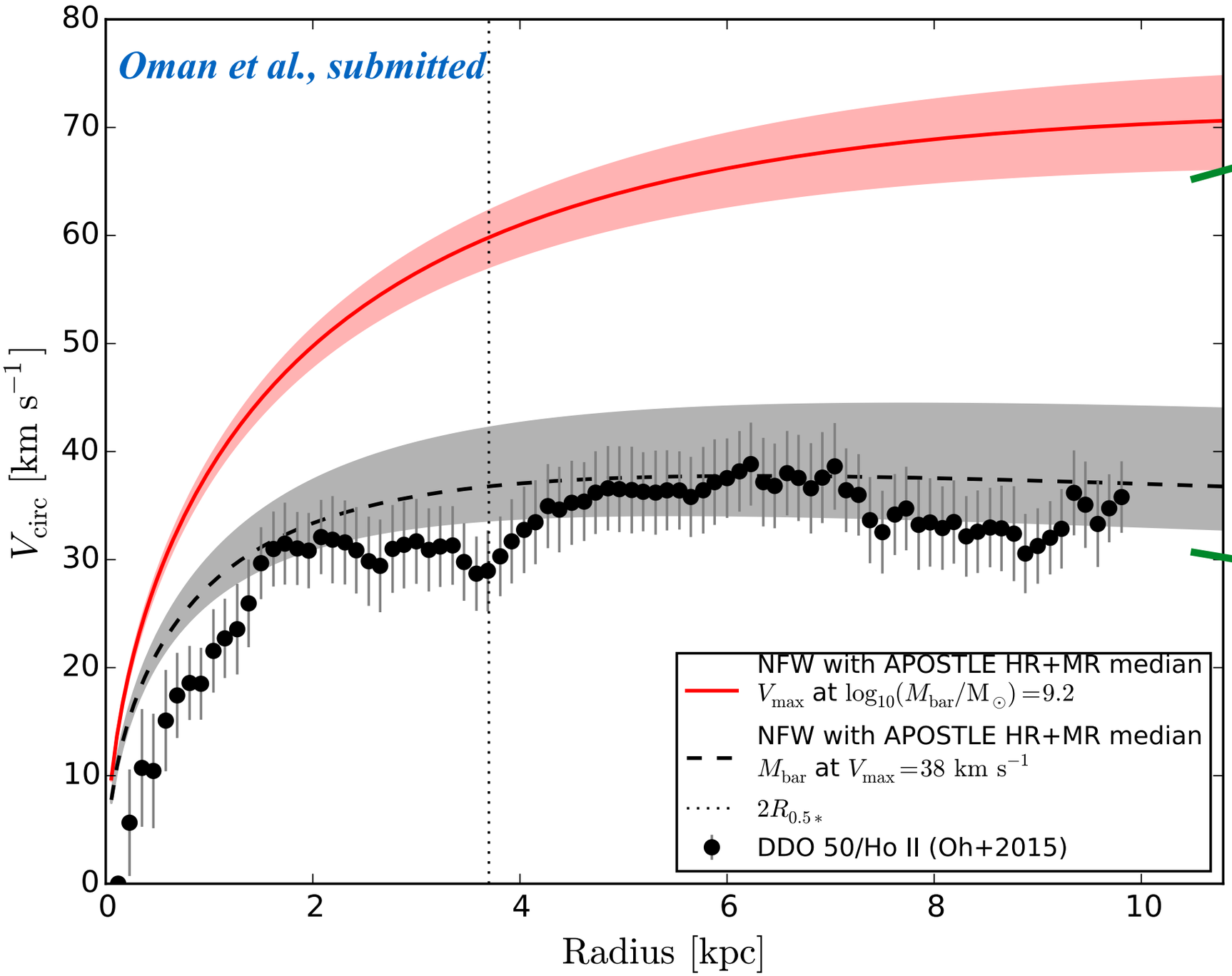
3. The Dark Matter content of Dwarfs



Close to 100% baryonic efficiency?

(Sales et al., submitted)

DM-deficient Dwarf Galaxies?

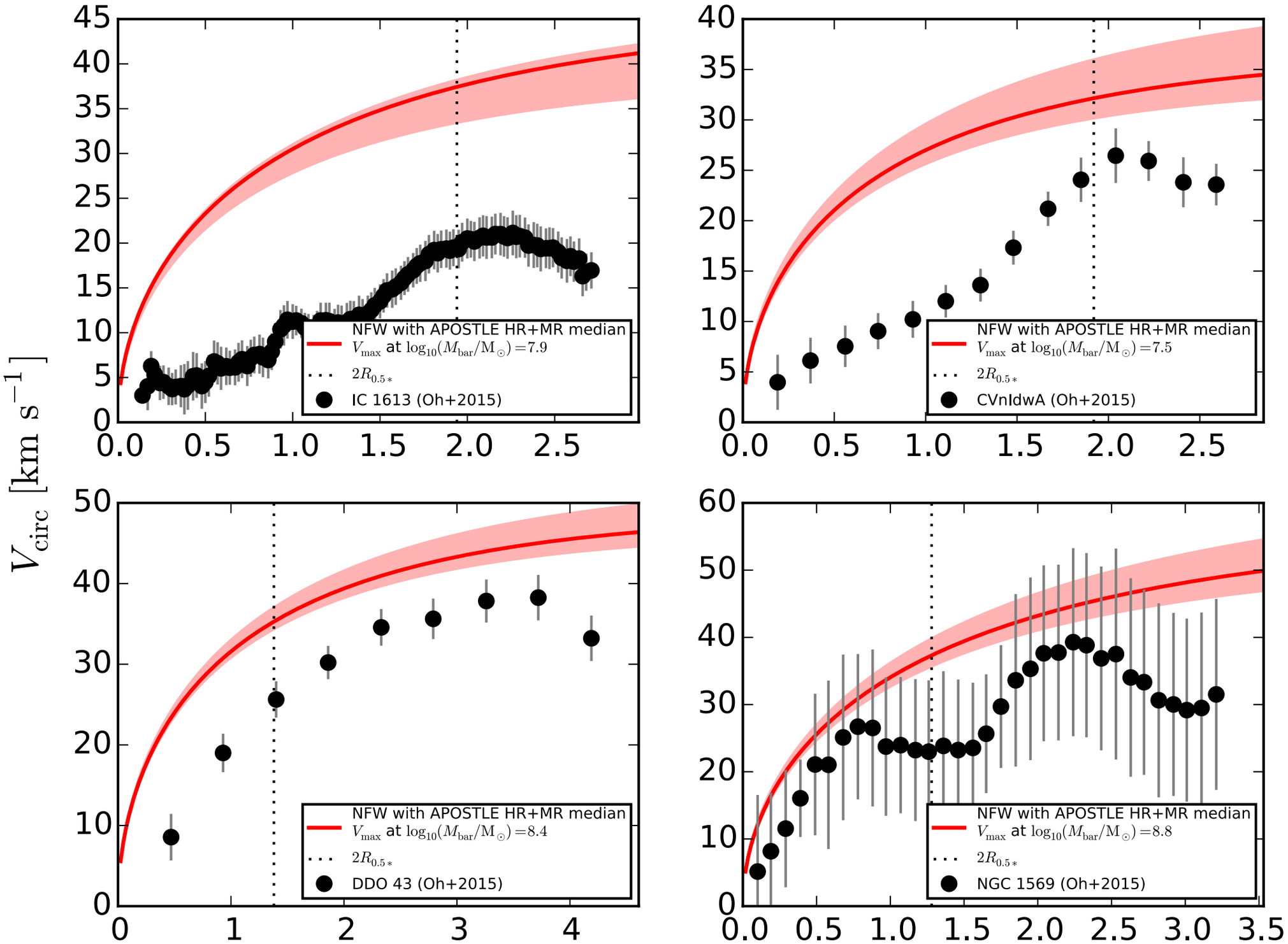


Expected halo given its baryonic mass

Halo consistent with kinematics

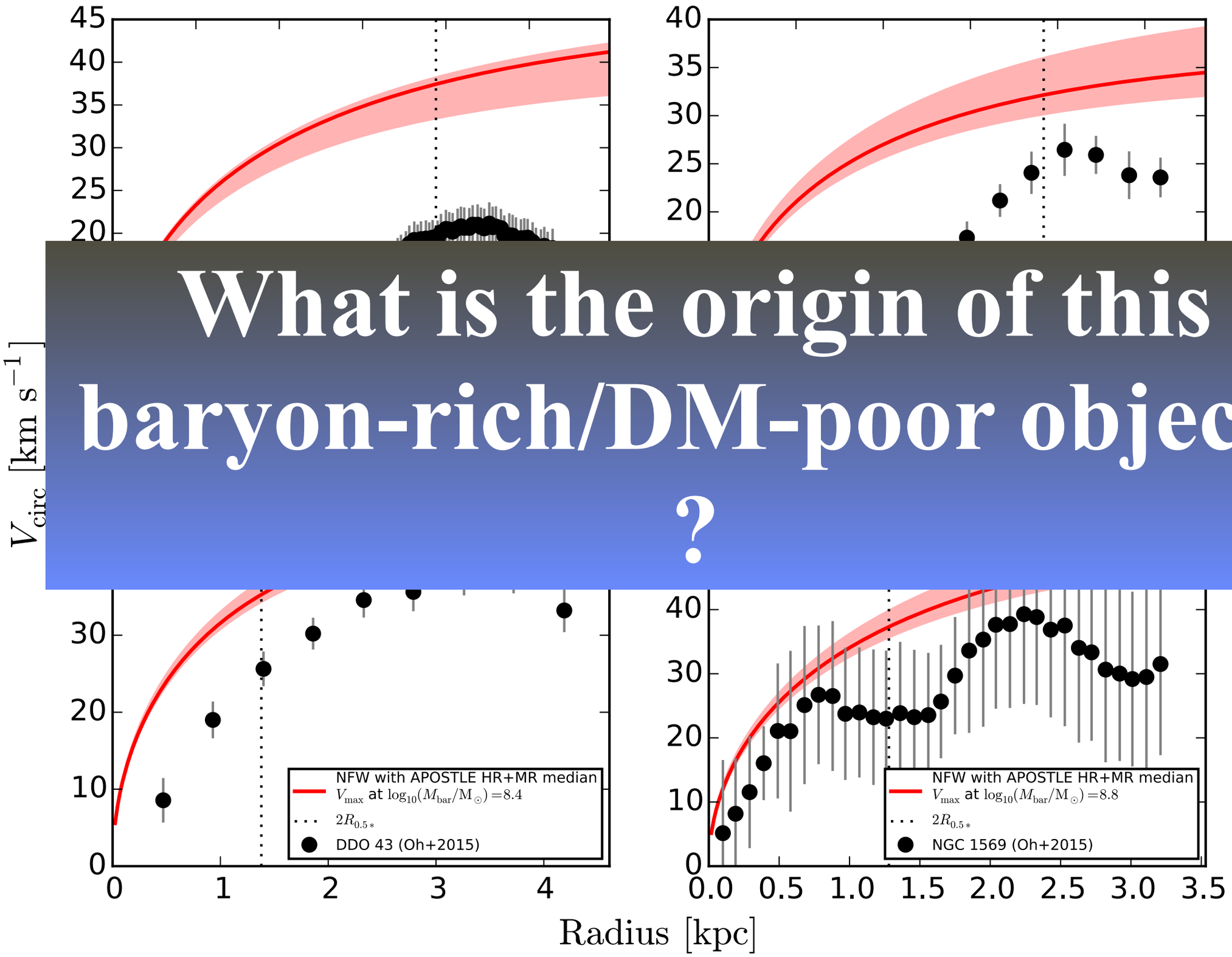
M_{bar} >100% available baryons in the halo

DM-deficient Dwarf Galaxies?



Oman et al., submitted

DM-deficient Dwarf Galaxies?



What is the origin of this baryon-rich/DM-poor objects ?

Oman et al., submitted

Conclusions

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- LCDM + galaxy formation models make a strong prediction: there should be satellite companions around all kind of galaxies, also dwarfs.

Dwarfs
Satellites

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Dwarfs Satellites

Dwarfs in clusters

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- Dwarfs ellipticals are consistent with being the descendant of field dwarf irregulars.

- We need better constraints to the M_{200}-M_* relation below $M^* \sim 10^8$ M_{sun}.

- The Baryonic Tully Fisher shows a large spread in the baryonic content of low mass dwarfs (1% to more than 100%)

- Origin of missing dark matter in dwarfs?

Dwarfs Satellites

Dwarfs in clusters

Dwarfs Baryon Content